# LOWER TERTIARY FORAMINIFERA FROM SOUTH EAST OMAN

BY

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## DECLARATION

This is to certify that the work submitted for the Degree of Doctoral of Philosophy (Phd) under the title:

LOWER TERTIARY FORAMINIFERA FROM SOUTH EAST OMAN

is of original work.

All authors and works are fully acknowledged.

No part of this work has been accepted in substance for any other degree, and it is not currently being submitted in candidature for any other degree.

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ABSTRACT

Over 250 samples were collected over three field seasons from the SE Oman Mountains. Forty-one species of planktonic Foraminifera (belonging to 7 genera) and twenty-eight species of larger benthonic Foraminifera (belonging to 13 genera) are figured (both by SEM and optical photography) from the Wadi Musawa and Wadi Suq sections. Nine planktonic foraminiferal zones are formally recognised between the Upper Palaeocene (P4) and upper Middle Eocene (P14). The known stratigraphic distribution of these species was used to recognise the zones P5, P8-P9 as equivalent to standard zones of Blow, 1969, 1979, whilst strata considered generally equivalent to P4 and P10-P14 in the Wadi Musawa section are zoned on the basis of the local range. Younger sediments can only be dated on larger Foraminifera. A possible hiatus representing the planktonic zones P6/P7 is tentatively identified. Fifteen lithostratigraphic units are recognised and formally described from three formations: the Abat Formation (units A-D), the Musawa Formation (units E-L) and the Tahwah Formation (units M-O).

The ages of the Abat and Musawa formations are redefined and are shown to be significantly older than previously published. Biostratigraphical and palaeoenvironmental data from both the planktonic and the larger Foraminifera has been used in conjuction with the lithostratigraphy to construct a sequence stratigraphy, in which several cycles have been recognised. Some of these cycles may correlate with the global sea-level cycles of Haq *et al.* (1987) and include TA2.3 and TA3.1, whilst others are local due to tectonically induced regressive and transgressive events. Information not only from the Foraminifera but also from radiolaria, ostracods and molluscs has been used to reconstruct the palaeoenvironment for the Omani Palaeogene. Parts of the Lower and Middle Eocene contain *in-situ* larger Foraminifera indicating deposition in a shelf (dominantly mid to outer) setting.

During the late Palaeocene, most of the early Eocene, part of the middle Eocene, and the entire late Eocene/early Oligocene mixed assemblages of planktonics and shallow water benthonics were the dominant Foraminifera. The occurrence of the these two assemblages in deepwater sediments indicates a substantial period of time in which penecontemporaneous uplift and resedimentation of carbonate shelf deposits into deeper water occurred. A number of new larger and smaller benthonic Foraminifera are described and one planktonic foraminifer renamed.

## *DEDICATION*

*To my Mother and my Wife and Daughter*

# *ACKNOWLEDGEMENT*

*Praise be to ALLAH (GOD), the Lord, has blessed me with countless: the support of my parents and my family, a pleasant environment in which to work, a generous sponsorship which provided security, a considerable supervisors whom were a pleasure to work with, friendly colleagues with whom one feels at ease.*

*In addition they have blessed me with more than sufficient life and energy to carry out this study. Thus, they first must be acknowledged for all these blessings and my countless thanks never be sufficient.*

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# *Introduction*

# *Chapter One*
# INTRODUCTION

## 1.1 AIM AND SCOPE OF STUDY

The purpose of this study was to produce a taxonomic, lithostratigraphical, biostratigraphical and brief palaeoenvironmental appraisal of the planktonic foraminiferal and larger foraminiferal fauna (plus a brief review of other microfauna including Radiolaria, charophytes, Ostracoda and, macrofossils) of the Lower Tertiary of the SouthEast Oman Mountains. This thesis concentrates mainly on the planktonic fauna which were only briefly mentioned by previous authors Roger *et al.* (1991), and the larger foraminiferal fauna which has been described in some detail by Racey (1988) and White (1989). The sedimentology and facies modelling of the Wadi Musawa Sequence is the subject of a separate Phd thesis (Al-Harthy, in prep.).

The late Palaeocene to early mid-Oligocene planktonic and larger Foraminifera from the Wadi Musawa and Wadi Suq sections were mentioned in Roger *et al.* (1991) but were not described or illustrated and no distribution chart was provided.

Previous works on other parts of the central and northern Oman Mountains have concentrated on the nummulitid, alveolinid and rotaliid assemblages typically found in the Lower Tertiary, particularly the Upper Palaeocene and Eocene. The primary objective of this investigation is to describe and illustrate the diverse planktonic foraminiferal assemblage together with selected larger Foraminifera. This represents the first major description of planktonic Foraminifera from the Tertiary of Oman.

The objectives of this study were as follows:

1- To describe and illustrate the lithology of the studied section.

2- To describe and illustrate the planktonic Foraminifera belonging to Globorotalidae and Globigerinidae present in the study sections.

3- To describe and illustrate selected larger Foraminifera belonging to *Nummulites, Operculina, Asterocyclina, Discocyclina, Daviesina, Alveolina, Neorotalia, Linderina, Lepidocyclina, Miscellanea, Coskinolina* and *Gypsina.*

4- To establish a zonation chart for the planktonic Foraminifera and to correlate this with standard published zones.

5- To use information provided by the micro and macrofossils present to reconstruct the palaeonvironments.

In the course of my field work, not only Foraminifera but also other microfossils (e.g. Radiolaria and ostracods) and macrofossils (molluscs and corals) were collected. These were identified by Drs Elspeth Urquhart (Radiolaria), M. C. Keen (ostracods) and N. J. Morris (molluscs) and provided important additional information on the stratigraphy and palaeoenvironmental interpretation of the studied sequence.

Identification of the planktonic Foraminifera involved the following procedures.
First of all, the various species, once isolated, were compared to the Palaeogene plankton illustrated in Postuma (1964, 1971) Stainforth et al. (1975), Toumarkine and Luterbacher (1985) and the Ellis and Messina *Catalogue of Foraminifera* (1940 etc).

Somewhat later, several visits were made to The Natural History Museum, London, to check them against the collections of Blow, Samanta and El-Naggar.

Finally, the provisional identifications were then discussed with one of my supervisors, Professor Haynes, before allotting a final name.

All the planktonic foraminiferal identifications are based on matrix-free material. In the Abat Formation (Upper Palaeocene planktonic foraminifera were commonly seen in thin section (see Plate 3.2.1.1a), but at this stage it was felt unwise to attempt to identify them. In many cases in the literature plankton have been miss-identified and I was advised by (Dr. J. Whittaker, pers. comm.) that this was a task for a specialist with many years experience.

## 1.2 GEOGRAPHICAL LOCATION OF OMAN AND STUDY AREA.

Oman lies on the eastern margin of the Arabian Peninsula and is bordered by the Gulf of Oman to the North and Arabian Sea to the East (Fig. 1.1). The study area (Wadi Musawa and Wadi Suq Sections) are located in the Ja'alan area to the South East of Muscat (Fig. 1.2).

## 1.3 GENERAL

Oman comprises three major geological provinces: the Oman Mountains in the north, Central Oman and the Dhofar region in the south. The Jabal Ja'alan area is situated in the SE Oman Mountains to the North of Huqf. The Oman Mountains are dominated by three Supersequences (A, B and C) and Basement according to Hanna, 1995 (Fig. 1.3).

In the Huqf area to the immediate south of the study area Supersequence A (SSA) and Supersequence C (SSC) are exposed around the Huqf Arch. Ophiolites and deep oceanic sediments of Supersequence B are absent but are exposed near the Batain Coast to the North and around Jabal Ja'alan. Jabal Ja'alan mainly comprises crystalline basement rocks, Hawasina equivalent sediments (SSB) and Tertiary sediments (SSC). Post-orogenic sediments of the Cretaceous Qalhat Formation (conglomerates) also outcrop in the area (Filbrandt *et al.*, 1990).

Although the geology of the Oman Mountains is dominated by the ophiolite and the geology of the Tethys Ocean, the Huqf area to the south is dominated by the Masira Line, which represents the onshore continuation of the offshore Owen Fracture Zone. Wrench tectonics associated with the probable onshore extension of this fracture zone represent the major tectonic regime during the Tertiary in the study area. Strike-slip faulting and associated structures (en-echelon folds) indicate a left-lateral (sinistral) movement along the major fault in the study area separating the Tertiary sediments from the underlying Ja'alan Complex. The logged sequenced represents a section measured along a limb of one of the major synclinal folds (Musawa Syncline) associated with this major feature (Fig. 2.3).

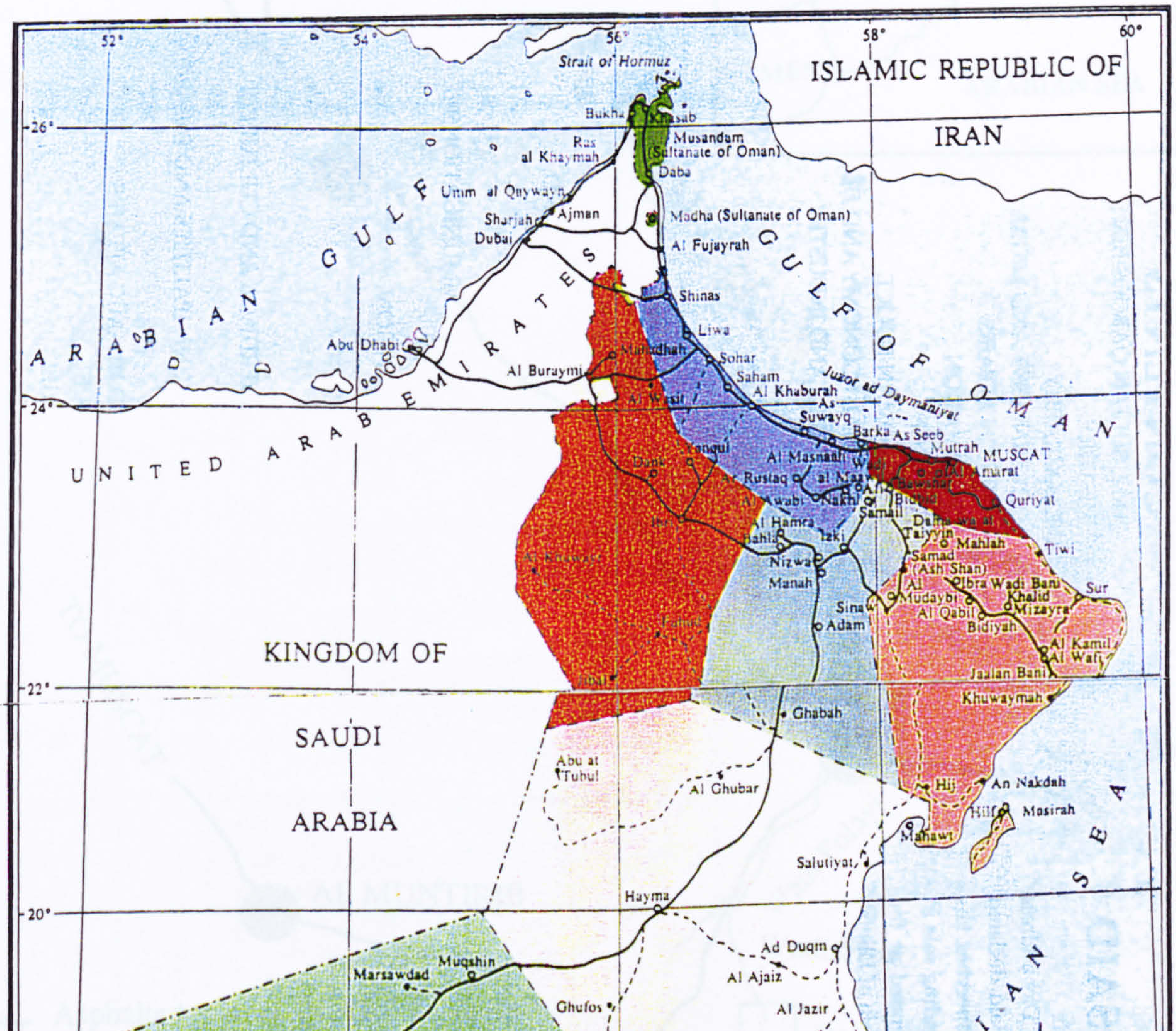



**Fig. 1.1 Geographical location of Oman (From Oman 1998/1999).**

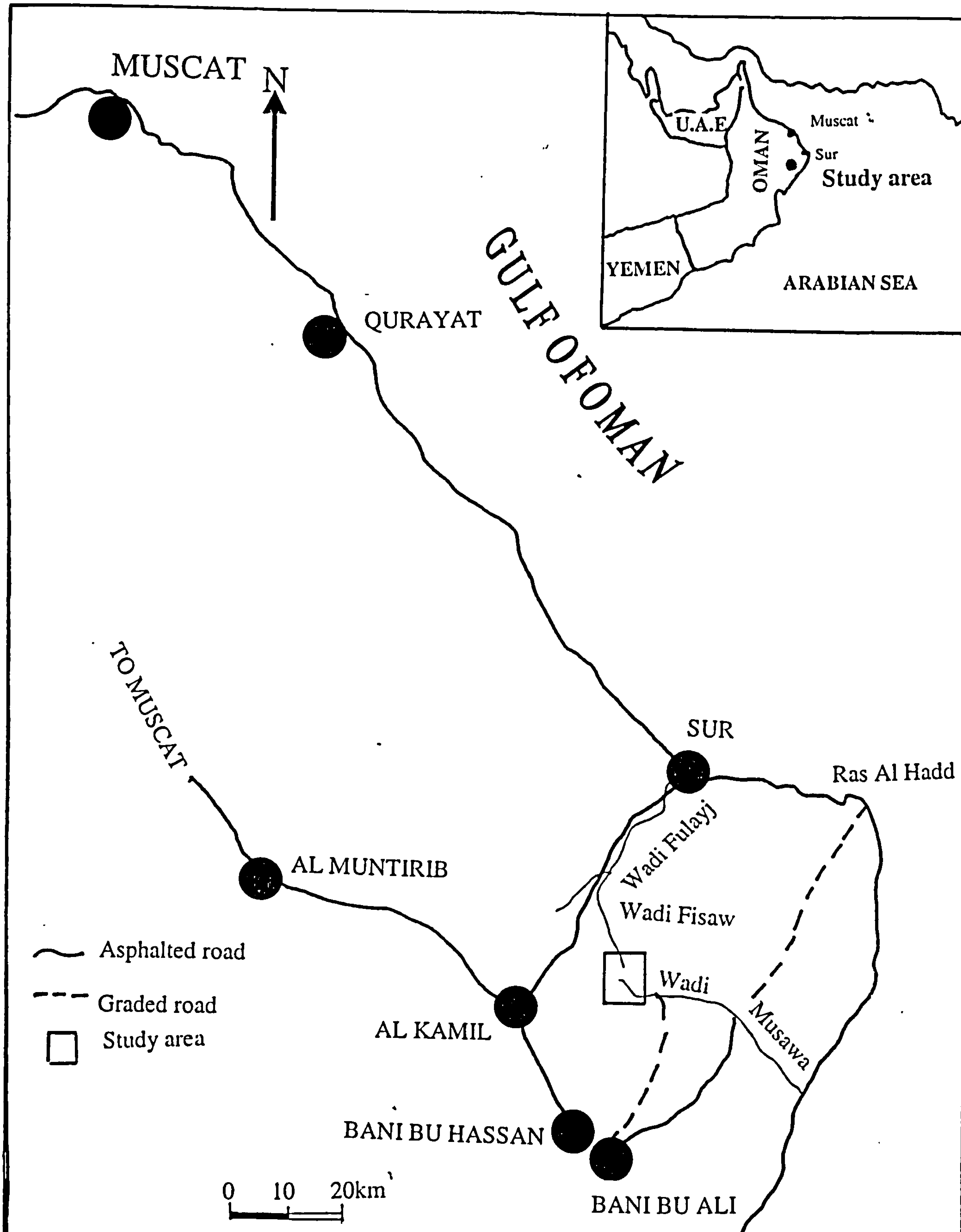



**Fig. 1.2 Location map of the study area.**

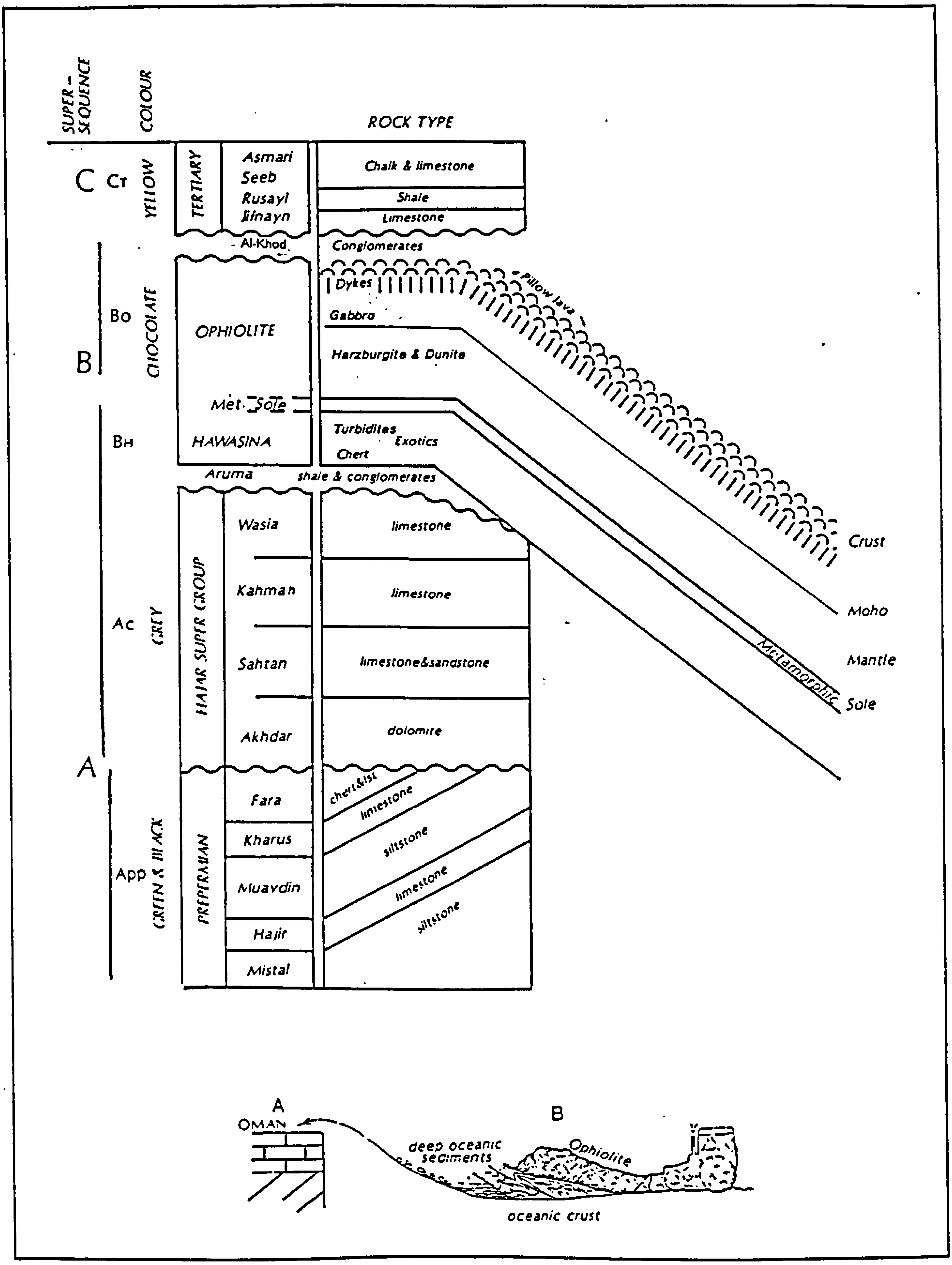



**Fig. 1.3 Three Supersequences of the Oman Mountains (after Hanna, 1995).**

## 1.4 GEOLOGICAL HISTORY:

Oman was originally part of the Gondwanaland Supercontinent, which fragmented into separate continents as it drifted southwards during the Permian and Mesozoic. The Afro-Arabian Plate moved southwards from Eurasia leading to the opening of the Tethys Ocean and formation of oceanic crust (Ophiolite). Sediments were deposited on the floor of this ocean and submarine volcanoes were abundant. Above these volcanoes (possibly on seamounts), shallow marine limestones were deposited (referred to as the Oman Exotics). The continental shelf of Arabia was transgressed by the Tethys Ocean and shallow marine limestones of Jurassic age (Hajar Supergroup) were deposited.

As the American plate moved away from Africa, the Atlantic Ocean began to open, causing Africa to reverse its direction of motion and move northwards resulting in the closure of the Tethys Ocean. This resulted in thrusting of Hawasina Group sediments and Semail Ophiolite landwards onto shallow marine limestones of the Hajar Super Group.

Following ophiolite emplacement in the late Cretaceous the area was exposed resulting in the deposition of near-shore to fluvial clastic sediments (Al-Khod Formation) which contain dinosaur remains, turtle bones and fossil wood indicating a dominantly tropical environment similar to that of present day East Africa. Laterites formed locally during this time on top of the Ophiolite.

During much of the Tertiary Oman was covered by a shallow sea resulting in the deposition of Tertiary Limestones and shales which are rich in marine microfossils and macrofossils. Rhythmic falls in sea level during the Tertiary resulted in the local deposition of coals at about 45 Ma in the Jabal Ja'alan, Al-Khod and Muscat areas. Although, the Oman mountains were formed as a result of major uplift in the Oligo-Miocene (25 Ma) their formation was initiated by the emplacement of the Semail ophiolite and deep ocean sediments almost 90 Ma (Hanna 1990). Uplift has continued until the present day and is evidenced by the raised beaches observed around the Muscat area.

## 1.5 PREVIOUS WORK:

Following the pioneering work of Lees (1928) and Allemann and Peters (1972), Glennie *et al.* (1974) produced the first geological map and description of the rock units and geologic history of the SE Oman Mountains. Subsequent studies by many research groups, including a consortium of mostly American scientists (Coleman 1981), the Open University (Lippard *et al.*, 1986), the Bureau de Rechearches Geologiques et Minieres (e.g. Villey *et al.* 1986a, Bechennec *et al.*, 1992) and oil industry funded earth scientists (Robertson *et al.*, 1990) have been undertaken. Le Metour *et al.* (1995) reviewed the geology of Oman, whilst Hanna (1995) produced a detailed guide to the field geology of the Oman Mountains. Filbrandt *et al.*, (1990) mapped the Jabal Ja'alan area as part of an oil consortium research project. The Ministry of Petroleum and Minerals Oman (MPM), published geological maps at 1:100,000 and 1:50,000 scales as a part of a geological mapping project with the Bureau de Rechearches Geologiques et Minieres (BRGM).

Publications on the Tertiary of the Oman Mountains include Nolan *et al.* (1986, 1990), who summarised and defined the Upper Cretaceous-Tertiary lithostratigraphy for SE Oman. Racey (1988; 1992a; 1992b; 1994 and 1995), described the lithostratigraphy, palaeoenvironments and biostratigraphy based mainly on nummulitids of the dominantly Palaeogene sequence of the Oman Mountains. Jones and Racey (1994) reviewed the sequence stratigraphy of the Tertiary of the Arabian Peninsula and produced a series of regional correlations and palaeogeographic maps.

Keen and Racey (1991), described the Lower Eocene ostracods from the Rusayl Shale Formation of Oman. Adams and Racey (1992) discussed the palaeobiogeographical significance of the foraminifer *Yaberinella* from the Eocene of Oman. Al-Sayigh (1992) described rotaliid Foraminifera from the Palaeocene/Eocene boundary of the Central Oman Mountains. White (1989, 1992 and 1994) established a foraminiferal biozonation for the SE part of Oman based mainly on *Alveolina*. White (1997) also described a new species of *Somalina* from the Lower Middle Eocene boundary of Oman.

A summary of previous stratigraphic work in Oman is given in Fig. 1.4, below:-

| AGE | FORMATIONS | | |
|---|---|---|---|
| | Oman Mountains | | Ja'alan Area |
| | Glennie, 1974 | Nolan, et al.,1986 | Roger, et al., 1991 |
| Late Eocene to Oligocene | Not recognised | Not recognised | Tahwah Fm. |
| Mid Eocene | Dammam Fm. | Seeb Fm. | Musawa Fm. |
| Early Eocene | Rus Fm. | Rusayl Fm. | |
| Late Palaeocene | Um Er Radhuma Fm. | Jafnayn Fm. | Abat Fm. |

**Fig. 1.4 Summary of previous work on the Tertiary**

## 1.6 Previous work on the Lower Tertiary planktonic Foraminifera from the Middle East and Pakistan.

### Saudi Arabia

Several studies have been carried out on the Palaeogene planktonic Foraminifera of Saudi Arabia.

El-Khayal (1974a) subdivided the Lower Hiber strata in subsurface of the Turyf area in the north-western Saudi Arabia, into six biostratigraphic zones these are from bottom to top: *Globorotalia pseudobulloides* Zone, *G. praecursoria* Zone, *G. angulata Zone, G. pusilla pusilla* Zone, *G. pseudomenardii* Zone and *G. velascoensis* Zone. Also El-Khayal (1974a) reported that the *Globorotalia uncinata* Zone is missing due to unconformity. El-Khayal (1974b) reported the occurrence of a planktonic Foraminiferal assemblage of Middle Palaeocene age in the El-Alat well, eastern Saudi Arabia.

The El-Alat well was chosen by El-Khayal to be a reference subsurface section for the biostratigraphic zonation of the Palaeocene of eastern Saudi Arabia. Subsequently, Hasson (1985) studied the lower part of the subsurface Umm er Radhuma Formation in the Rub' al Khali basin. She also recorded an assemblage of planktonic Foraminifera (Lower Eocene) in the succession, which directly overlies the top of the Aruma Formation of Late Cretaceous age. Hasson (1985) re-examined the planktonic Foraminifera of the El-Alat well, which was considered by El-Khayal (1974) of

Palaeocene age, and placed them in the *Globorotalia pseudomenardii Zone*. El-Naggar and Kamel (1988) carried out a biostratigraphical analysis of the Upper Cretaceous-Lower Palaeogene succession in the Turayf area, northwestern Saudi Arabia. They recorded a planktonic foraminiferal assemblage in the Hiber Group, which was assigned to the *Globorotalia* (*Acarinina*) *wilcoxensis beggreni* Zone of Blow (1979), indicating a latest Palaeocene-earliest Eocene age. El-Naggar and Kamel (1988) reported that none of the planktonic foraminiferal zone markers used by El-Khayal (1974a) in his biostratigraphic zonation of the Hiber strata was recorded in the early Palaeogene succession in the Turayf area, northwestern Saudi Arabia.

**United Arab Emirates**

Hamdan and Deeb (1990) subdivided the Palaeogene succession of Jabal Malaqet into the Pebdeh "Equivalent" Formation (Middle Palaeocene-Middle Eocene) and the Dammam Formation (Late Eocene) and established a biostratigraphic zonation based on planktonic and larger benthonic Foraminifera. Anan and Hamdan (1993) described Palaeocene planktonic Foraminifera from Jabal Malaqet east Al- Ain U.A.E. and recognised three planktonic foraminiferal zones including *Morozovella angulata* Zone (P3a), *Planorotalites pseudomenardii* Zone (P4) and *Morozovella velascoensis* Zone (P5).

**Pakistan**

Haque (1956) noted the presence of planktonic Foraminifera within the lower Laki (Lower Eocene) Formation. He assigned a Late Palaeocene age to *Globorotalia velascoensis*. Later Haque (1956) recorded *Globorotalia velascoensis* as occurring with the Lower Eocene species *Globorotalia aragonensis* and *Globorotalia wilcoxensis*. Samanta (1973) recorded eight zones from the Palaeocene-Eocene) succession in the Rakhi Nala, Suleiman Range, Pakistan."

## 1.7 METHODOLOGY

**1.7.1 SAMPLING METHODS:** The sections studied are located in the SE Oman Mountains (Fig.1.1). Sampling of the Wadi Musawa section was undertaken in April 1994, June 1995 and January to March 1996. Two hundred and fifty seven samples were collected. All samples including hard limestone were processed. One hundred and sixty five samples were used for making random thin sections. One hundred and two isolate d specimens were thin sectioned at the Natural History Museum under the guidance of Richard Hodgkinson (see appendix 1).

The following sampling procedure was adopted in the field:

***Sample spacing:*** The measured section was sampled at one metre spacings with additional samples taken of any new lithologies which would be missed by this spacing. Where possible only unweathered rocks were sampled. Any macrofossils present were systematically labelled, collected and taken to the Natural History Museum London for identification. Lithological logs were drafted for identification with sample numbers. The Wadi Musawa section was subdivided into three formations namely the Abat, Musawa and Tahwah and several lithological units, the Wadi Suq section only composed partly the Tahwah Formation.

Each sample and its location was given a code number. e.g. WM-1 to WM-75 WME-75 to WME-242 for Wadi Muswa and, WS for nearby Wadi Suq. A few additional samples were also collected late r from the middle of the section and given code numbers prefixed WMC-12 to WMC-23. The sections were sketched and panoramic photographs and slides were taken.

**1.7.2 PREPARATION**

The main lithologies (shale, marl, limestone, sandstone, mudstone, siltstone, and coal) were processed as follows:-

1- ***Crushing and boiling:*** Each sample was crushed carefully so as not to break it into fragments smaller than the larger Foraminifera present i.e. 2mm-1cm diameter. To avoid contamination from previous workers a blue dye was used to stain the sieves thus showing any foreign materials.

After crushing, each sample was washed, placed in a non-aluminium container and then immersed in a beaker of water containing Hydrogen-Peroxide or White Spirit over night. This mixture was boiled for several hours, in some cases more than two days until the particles disaggregated. However, because some samples were hard and well-cemented they required boiling for more than one day. After boiling the samples were placed on filter paper to dry.

2- ***Washing and sieving:*** The object of washing and sieving is to clean the specimens and remove all particles smaller than mature Foraminifera. For this reason a 150 micron sieve was chosen. Juvenile Foraminifera, the taxonomic position of which are difficult, or impossible to determine were also removed during this processes. The sieve size was selected according to the faunal content. The passage of particles through the sieve was aided by a flow of water; thus the material was simultaneously washed and separated into size fractions.

*3- **Drying:*** The samples were dried in an oven overnight.

*4- **Final sieving:*** Once dried the whole sample was sieved into four different fractions (approximately 500, 250, and 150microns) with each fraction placed in a small bottle, and labelled both on the outside and inside.

*5- **Picking:*** The Foraminifera were picked using a moistened artist's brush of 00 or 000 size and transferred to a cavity slide for further examination. Picking concentrated on mesh sizes 30, 60 and 100 (respectively 500, 250 and 150 micron) while any thing smaller than 100 mesh size was left as it consisted of badly preserved and small Foraminifera.

*6- **Sorting and identification:*** The specimens were sorted and placed on faunal grid slides for late r identification.

*7- **Storage:*** Surplus materials were placed in labelled plastic bags for future reference.

### 1.7.3 PROBLEMS IN PREPARATION:

Some samples were very hard and well cemented, therefore, to obtain acceptable degrees of disaggregation they required excessive boiling. Several alternative techniques (see below) were tried for such samples but very few were successful.

### 1.7.4 TECHNIQUES EMPLOYED TO BREAK DOWN SAMPLES:

Techniques used to disaggregate samples included deep freezing and boiling, boiling with white spirit or hydrogen-peroxide, ultrasonic cleaning, and heating.

1- ***DEEP-FREEZING AND BOILING***: Samples were kept in a freezer for two days then placed in boiling water.

2- ***WHITE SPIRIT:*** Samples were soaked in white spirit for 48 hours then boiled.

***3-HYDROGEN PEROXIDE:*** Samples were soaked in hydrogen peroxide (20%) over night to remove the grains and other materials and to breakdown hard limestones.

***4- ULTRASONIC:*** Picked specimens were placed in a beaker or a small bottles and then put in an ultrasonic bath for a few minutes to clean the specimens.

***5-HEATING:*** Samples were heated until they were glowing red often over several hours and were then placed into cold water.

During the subsequent sorting process it was noted that parts of the tests were often obscured by adhesive sediment. Ultrasonic cleaning techniques were found to best remove these tiny particles, particularly those situated between pillars or pustules and bars on both sides of the foraminiferal test. Some specimens especially the larger Foraminifera required more than 15 to 20 minutes of treatment whilst smaller forams and planktonic Foraminifera required less than 15 minutes.

**1.8 SEM PREPARATION*:*** The best preserved specimens were selected for viewing and photographing under the SEM. Preparation for the SEM followed standard techniques in which specimens were mounted on exposed negative film on aluminium stubs using double sided tape, and coated with 120A of gold alloy in a sputter coating unit.

## 1.9 PROBLEMS:

Detailed published micropalaeontological research on the Tertiary sequence of Jabal Ja'alan area does not exist save for a very brief descriptions by Glennie (1974), Filbrandt *et al* (1990) and Roger *et al* (1991). The sequence differs from the Tertiary of the Mountains to the north due to its proximity to a major strike-slip fault, which mainly controlled sedimentation and thus fossil assemblages throughout much of the Tertiary (Hanna, pers. comm.; Racey pers. comm.).

Age determination and environmental assessment for this sequence, which is characterised by syndepositional tectonism, resedimentation and localised reworking, and which shows a wide range of facies variation over short distances, proved to be major problems during this study.

Major almost geological instantaneous changes in lithology and environment typical of strike-slip basins were frequently observed in Wadi Musawa area often involving changes from marine to non-marine facies (see Chapter 3 for detail). These dramatic variations in lithology and fauna can be satisfactorily explained by major structural movements (Wright, Hanna and Racey, pers. comm.). Within the measured section studied there are both significant intervals of no exposure plus other intervals dominated by sediments lacking age diagnostic faunas (mainly non-marine intervals). Consequently, there is significant potential for the presence of as yet unidentified, depositional breaks in the sequence.

A strong structural control on sedimentation has been mapped by Hanna *et al.* (in prep), which shows that the bottom of the basin has effectively fallen dramatically with associated rapid marine transgression. Conversely occasional major pop-up structures typical of strike-slip basins are also observed by Hanna *et al.*, and these are associated with major albiet local tectonically driven "regression" (Hanna *et al.*, in prep). Superimposed over top of this are the effects of eustatic sea-level changes. The studied area fills a geographic gap in knowledge between the Tertiary of the SE Oman Mountains and the Huqf and Dhofar regions to the South.

# Chapter Two

# Geology of Jabal Ja'alan Area

# Chapter Two

## GEOLOGY OF JABAL JA'ALAN AREA

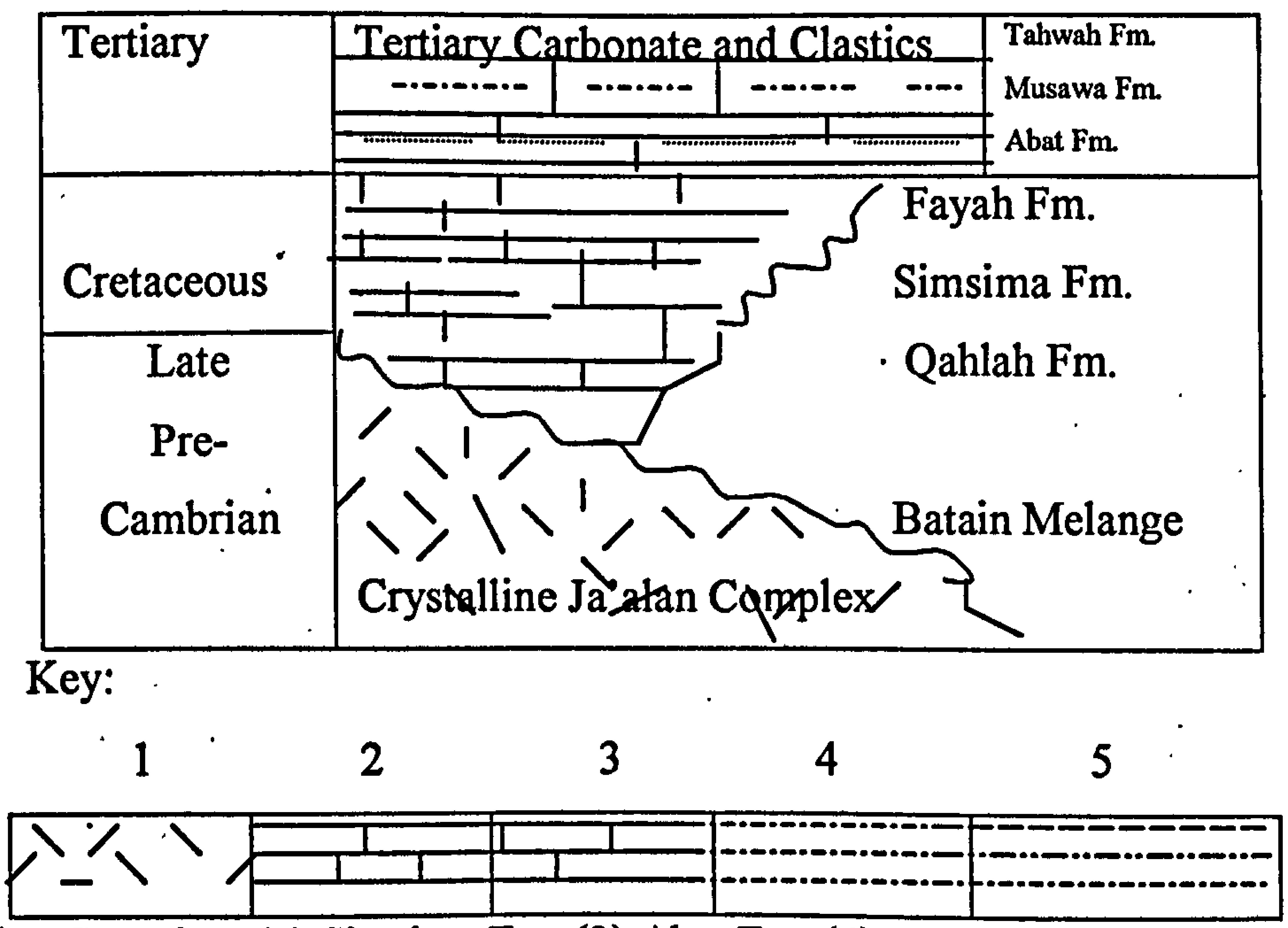
### 2.1 INTRODUCTION

The studied section is broadly equivalent to those sections studied by Roger, *et al.*, (1991). They assigned the Abat Formation to the Lower Ypresian to the middle part of the Lutetian based on their identification of the fauna. The Musawa Formation was dated by Roger, *et al.* (1991) as Upper Lutetian to Upper Bartonian whilst the Tahwah Formation was considered to be Mid-Priabonian to Oligocene. However, in the present study the Abat and Musawa formations are considered to range younger, based on planktonic and larger Foraminifera, while the age of Tahwah Formation is considered to be the same as recorded by Roger, *et al.* (1991). (see Chapter Three for detail).

### 2.2 *Stratigraphy and Tectonics of Jabal Ja'alan*

#### 2.2.1 *Stratigraphy*

The various lithostratigraphical units exposed in Ja'alan area are summarised in the following diagram (Fig. 2.1):




(1) Ja'alan Complex. (2) Simsima Fm. (3) Abat Fm. (4) Musawa Fm. (5) Tahwah Fm.

**Fig. 2.1 Stratigraphy of the Ja'alan area.**

**a) JA'ALAN COMPLEX**

Exposures of the Precambrian Jabal Ja'alan Complex are limited to structural highs within the Oman Mountains. The Jabal Ja'alan Complex comprises Upper Precambrian to Lower Palaeozoic mica schists, gneisses, amphibolites, granites and dykes. (Glennie *et al.*, 1974; Gass *et al.*, 1990). The Ja'alan gneisses, include banded biotite-garnet-quartz-feldspar gneiss and migmatites whilst the Al-Wafi schists include banded biotite-sillimanite-mica-schist and plutonics.

**b) BATAIN MELANGE**

The Batain Melange outcrops over an area of 250x70 Km between the Batain coast and the Wahiba Sands and comprises Permian Qarari Limestones, green gniess, Triassic limestones, mega-breccias, basalts and white, pink and red bioclastic limestones of uncertain Triassic age (Shackleton *et al.*, 1990).

**c) QAHLAH FORMATION**

The Qahlah Formation unconformably overlies the peneplained crystalline basement of the Jabal Ja'alan complex and varies in thickness from 80 m on the east side of Jabal Ja'alan, to <10 m at Jabal Qahwan. It comprises unfossiliferous, interbedded red and yellow pebbly chert conglomerates, lithic sandstones, shales and marls of mainly fluvial origin. The chert clasts were probably derived from the Hawasina Complex. Clasts from the underlying Precambrian basement are very rare; suggesting that the basement was not exposed during Qahlah times and was most likely covered by the Hawasina Complex. Bioturbated marine limestones occur towards the top of the sequence.

The Qahlah Formation has not been accurately dated but is unconformably overlain by Maastrichtian limestone of the Simsima Formation (Fig 2.4). At the type locality of Qahlah, 50 km to the north, the upper part of the Qahlah Formation was dated as Maastrichtian (Glennie *et al.*, 1974) based on a comparison with its equivalent post-orogenic sediments in the mountains.

**d) SIMSIMA FORMATION.**

The Simsima Formation comprises cliff forming, massive to well-bedded, often nodular, pale yellow to grey bioclastic shallow marine shelf limestones which generally lack terrigenous sediment (Fig. 2.5). The lowermost 10 m are often marly whilst thin marl interbeds occur throughout the formation.

The formation contains rudist bivalves, including *Vaccinites* sp., *Durania* sp., *Biradiolites* sp., and *Dictyoptychus* sp., many of which are preserved in life position. These are particularly frequent in the lower parts of the unit. The giant benthonic foraminifer *Loftusia* sp. is locally very abundant. The presence of *Dictyoptychus* sp., and *Loftusia* sp. dates the Simsima Formation as Maastrichtian (Skelton *et al.* 1990).

In the Qalhat area similar limestones, of unknown thickness overlie the Qahlah Formation and may also be assigned to the Simsima Formation. SSW of Qalhat, the Jafnayn Formation overlaps the Simsima Formation and onlaps the Hawasina Complex e.g. at Wadi Bani Khalid.

**e) TERTIARY**

Only regional reconnaissance mapping has been undertaken previously on the Tertiary sequence of the Jabal Ja'alan area [Filbrandt *et al.* (1990); Shackleton *et al.*, (1990) and the BRGM (Roger *et al.*, 1991)]. The Tertiary sediments in the western part of the Ja'alan area are mainly exposed in a narrow band along the western edge of the hills. The base of the Tertiary in the western Ja'alan area rests disconformably upon the Simsima Formation and is rarely exposed. In the North Central area which forms the study area, the Tertiary generally overlies the Hawasina Nappes and Maastrichtian sediments. In the Northern Area the Tertiary sequence is more limited in outcrop and is much thinner.

The details of the Tertiary sequence in the North Central area are given in section (2.2). A summary of the Lower Tertiary of the Oman Mountains as compared to the Ja'alan area is given below:

| OMAN MOUNTAINS | | | JA'ALAN AREA | |
|---|---|---|---|---|
| Age | Glennie, 1974 | Nolan, 1986 | Roger, 1991 | This study |
| Late Eocene to Early Oligocene | | | Tahwah Fm. | Tahwah Fm. |
| Mid Eocene | Dammam Fm. | Seeb Fm. | Musawa Fm | Musawa Fm. |
| Early to Mid Eocene | Rus Fm. | Rusayl Fm. | | |
| Late Palaeocene to Early Eocene | Um-Er Radhuma Fm. | Jafnayn Fm. | Abat Fm. | Abat Fm. |

**Fig. 2.2 Lower Tertiary stratigraphy of the Northern Oman Mountains as compared to the present study area.**

### 2.2.2 Tectonics:

The Jabal Ja'alan area was subjected to a number of tectonic events from the Pre-Cambrian to the Tertiary:

1- Precambrian deformation shown by intensive folding and shear zones in the Ja'alan Complex.

2- Early Alpine deformation shown by the emplacement of the Hawasina equivalent onto the Ja'alan Complex during the Cretaceous (This corresponds to ophiolite emplacement in the Oman Mountains).

3- Late Alpine Tertiary deformation along a strike-slip system associated with the Owen Fracture Zone (Masira line). The folds associated with this fault indicate a left-lateral or sinistral sense of movement (Fig. 2.3). The measured section lies in the Musawa syncline which forms one of these folds.

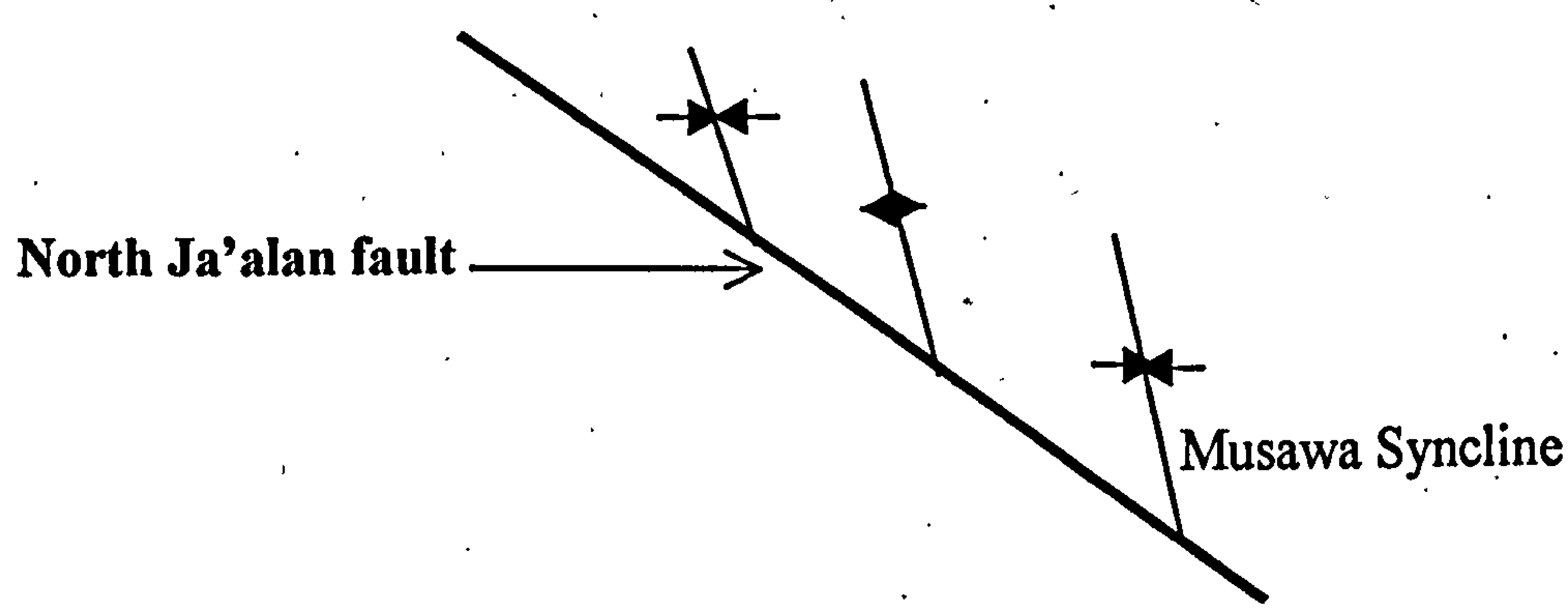



**Fig. 2.3 North Ja'alan fault and associated en-echelon folds.**

## 2.3 WADI MUSAWA AND WADI SUQ SECTION

The Wadi Musawa and Wadi Suq sections represent the focus of this study and comprise the following Formations (based on Roger *et al.*, 1991).

**1-Fayah Formation:**

This comprises turbiditic sandstones of early Maastrichtian age imbricated with the Hawasina Nappes and outcrops to the north of the mouth to Wadi Musawa on the eastern slope of Jabal Khamis. The sediments form decimetre-thick beds and are similar to those exposed to the east of Jabal Ja'alan and Jabal Qahwan in the southern area, which were assigned to the Fayah Formation by Filbrandt *et al.* (1990).

**2- Abat Formation**

The Abat Formation in Wadi Musawa unconformably overlies Maastrichtian turbidites of the Fayah Formation. To the northeast and northwest of Wadi Musawa the formation may also unconformably overlie the Hawasina Nappe. Roger *et al.* (1991) described the Abat Formation as having variable thickness from less than 50 m (northwards in the Tiwi map) to more than 400m (north of Jabal Nujud). In the (BRGM) Roger *et al.*, (1991) formation classification, the Abat Formation in Wadi Musawa (Fig. 2.6) begins with 14 m of thinly interbedded resistant lime mudstone and shale a decimetre scale which are separated by an unconformity from an overlying 9m thick sequence of partly-silicified packstone to grainstone. This passes upwards into 17m of calciturbidite. Five calciturbidite flows separated by erosive basis can be recognised, grading from calcirudite to calcarenite and ending with calcilutite. Overlying this are 15m of interbedded lime mudstone and shale on decimetre scale.

The Abat Formation ends with at least 12m of resistant highly fossiliferous bioclastic grainstone and packstone. Thin section analyses (see Chapter 3) show that the Abat Formation starts with basinal deposits rich in planktonic Foraminifera. The sequence then passes upwards to turbidites and slope deposits environment and is capped by shelfal grainstones to packstones. The sequence thus shallows upwards before passing into the Musawa Formation which starts with a basal conglomerate of probable fluvial origin.

**3- Musawa Formation**

The Wadi Musawa Formation is divided into three Members by (Roger *et al.*, 1991) as follows (Fig. 2.7):-

**a) Lower Sandstone Member**

This consists of >350m rusty to whitish sandstone and siltstone with subordinate conglomerates

**b) Middle Carbonate-Marl Member**

This unit comprises 500m of alternating marls and carbonates with sporadic and limited detrital influx. The member starts with a basal grey coloured limestone overlain by a carbonate unit, which has a low fossil diversity and contains gypsiferous mudstone and gypsum. These are cut by randomly oriented medium to fine grained sandstone channels.

**c) Upper Sandstone Member**

A 250m thick whitish to purple coal-bearing sandstone and siltstone with micritic limestone interbeds.

**Environment**

Roger *et al.* (1991) suggest that the lower member is deltaic in origin observing that: "The deposits thus form a regressive megasequence passing from the slope deposits of the Abat Formation to open marine coarse clastic deposits, a megasequence reflecting the progradation of the deltas over the slope".

**4- Tahwah Formation**

The contact between the Tahwah and Musawa formations is always sharp and generally occurs at a palaeo-canyon erosion surface (Fig. 2.8). The formation forms the southern side of the Wadi Musawa-Wadi Fisaw Syncline and is bounded by the North Ja'alan fault to the south.

The formation shows rapid lateral facies and thickness variations. In general it consists of bioclastic limestone, polymict breccia, green marl, olistolith (big clasts) and reworked coral breccia. The sequence was interpreted as representing slope deposits with palaeo-channels which eroded the underlying units and deposited them as breccias and olistoliths by Roger *et al.*(1991).

Roger *et al.* (1991) assigned the Abat Formation to an early Ilerdian to early/mid Lutetian age based on their identification of the contained fauna. The age of the Musawa Formation given by Roger, *et al.* (1991) is late Lutetian to late Bartonian while the Tahwah Formation is dated as Mid Priabonian to Oligocene. However, in the present study the age of these formations differs slightly based on the contained planktonic and larger Foraminifera. The results of this revised dating with respect to formation boundaries are outlined in the following Chapter 3.

### 2.4 REGIONAL CORRELATION

The classification of the lithostratigraphy of the western Oman Mountains by Jones and Racey (1994) differs from that erected in this study as shown in (Fig. 2.9) and discussed in (Chapter Three). However, the lower Jafnayn Formation is equivalent to the Abat Fomation, whilst the upper Jafnayn formation is equivalent to the lower Musawa Formation. The Rusayl Formation is equivalent to the Musawa Formation, whilst the Pabdeh and Seeb Formations span to the Musawa and Tahwah Formations. The Al Jaww Formation is equivalent to the upper part of the Tahwah Formation (Fig. 2.9).

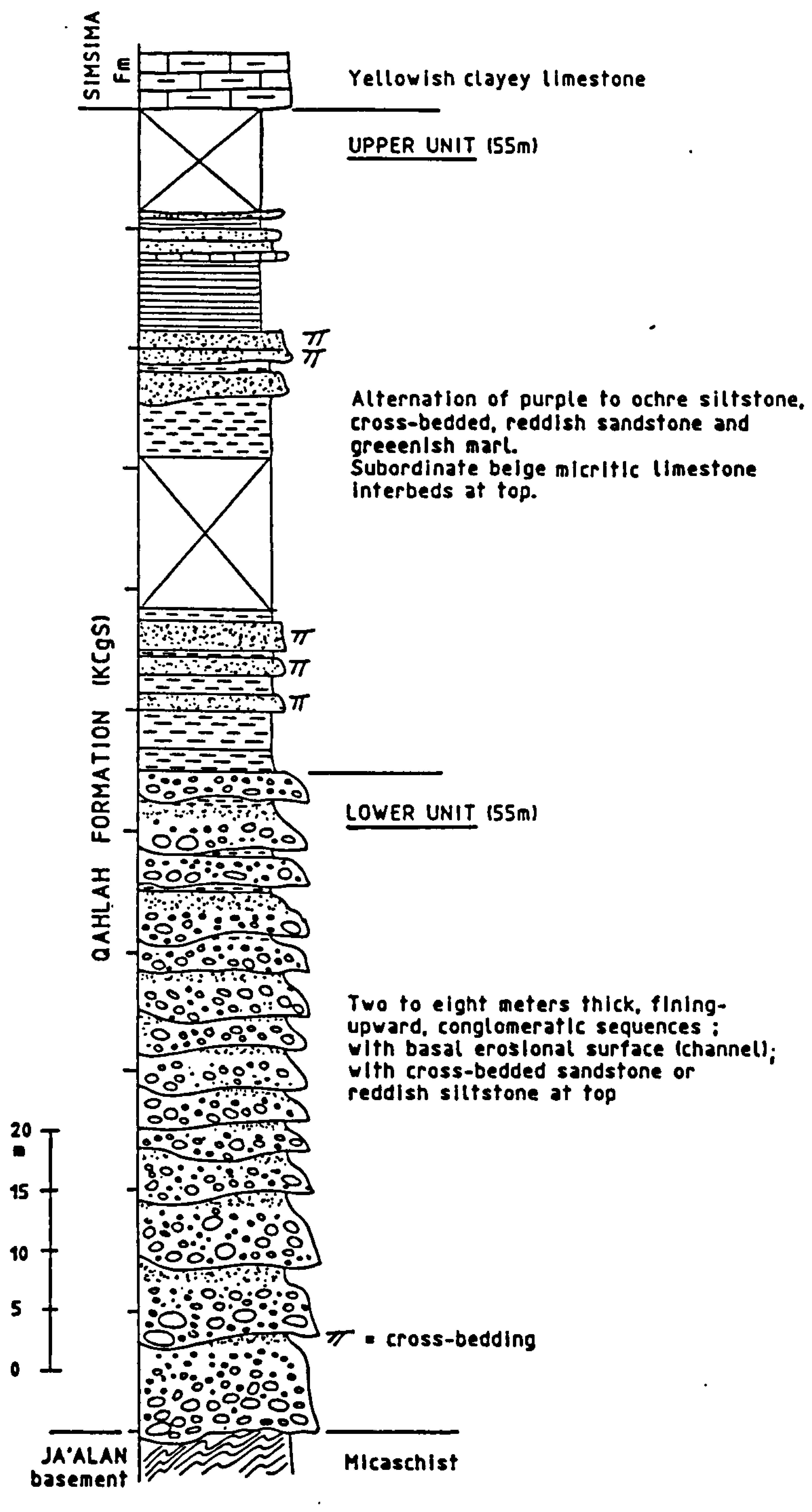



**Fig. 2.4 Lithostratigraphic column for the Qahlah Formation (after Roger *et al.*, 1991)**

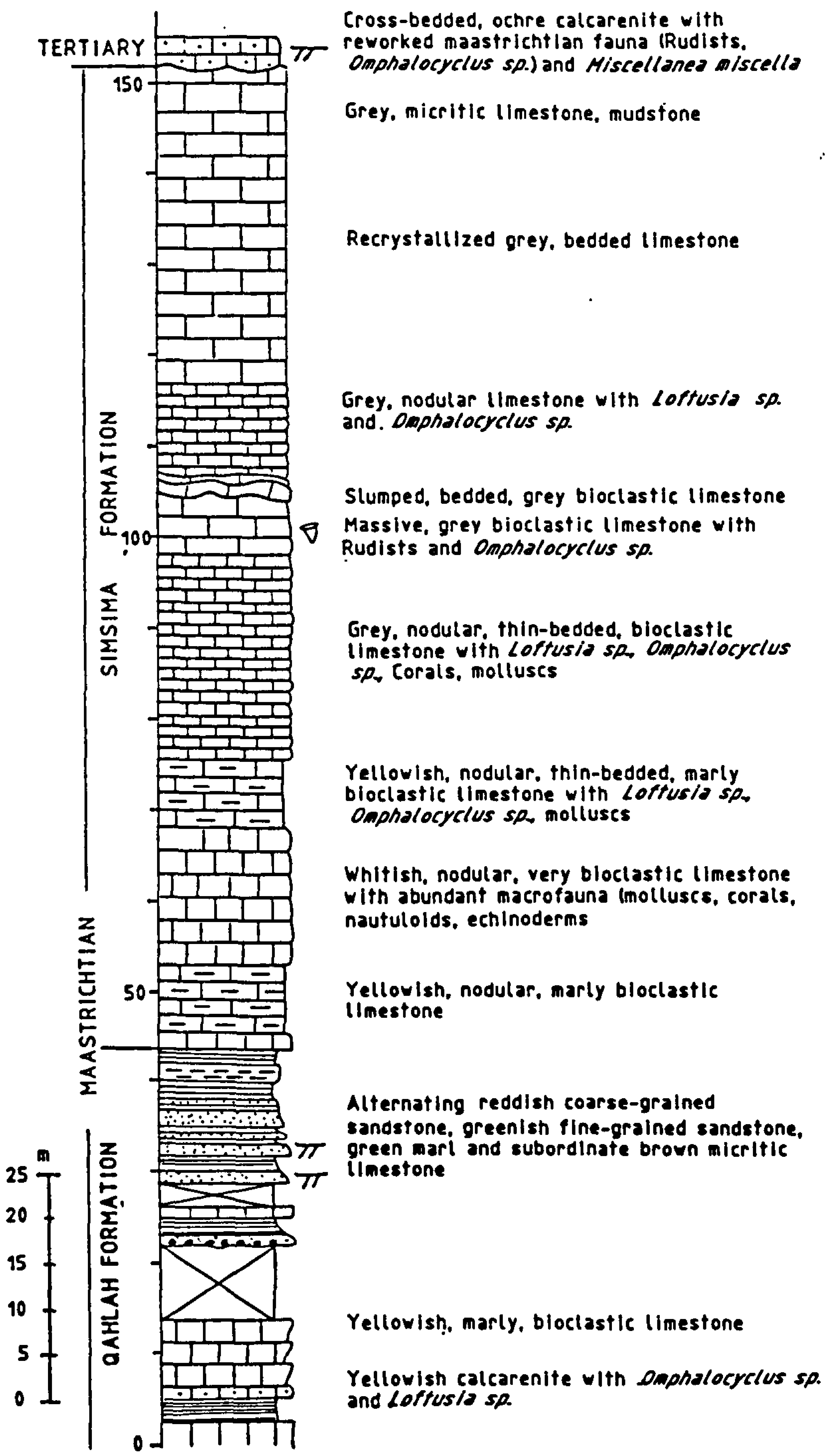



**Fig. 2.5 Lithostratigraphic column for Simsima Formation (after Roger *et al.*, 1991)**

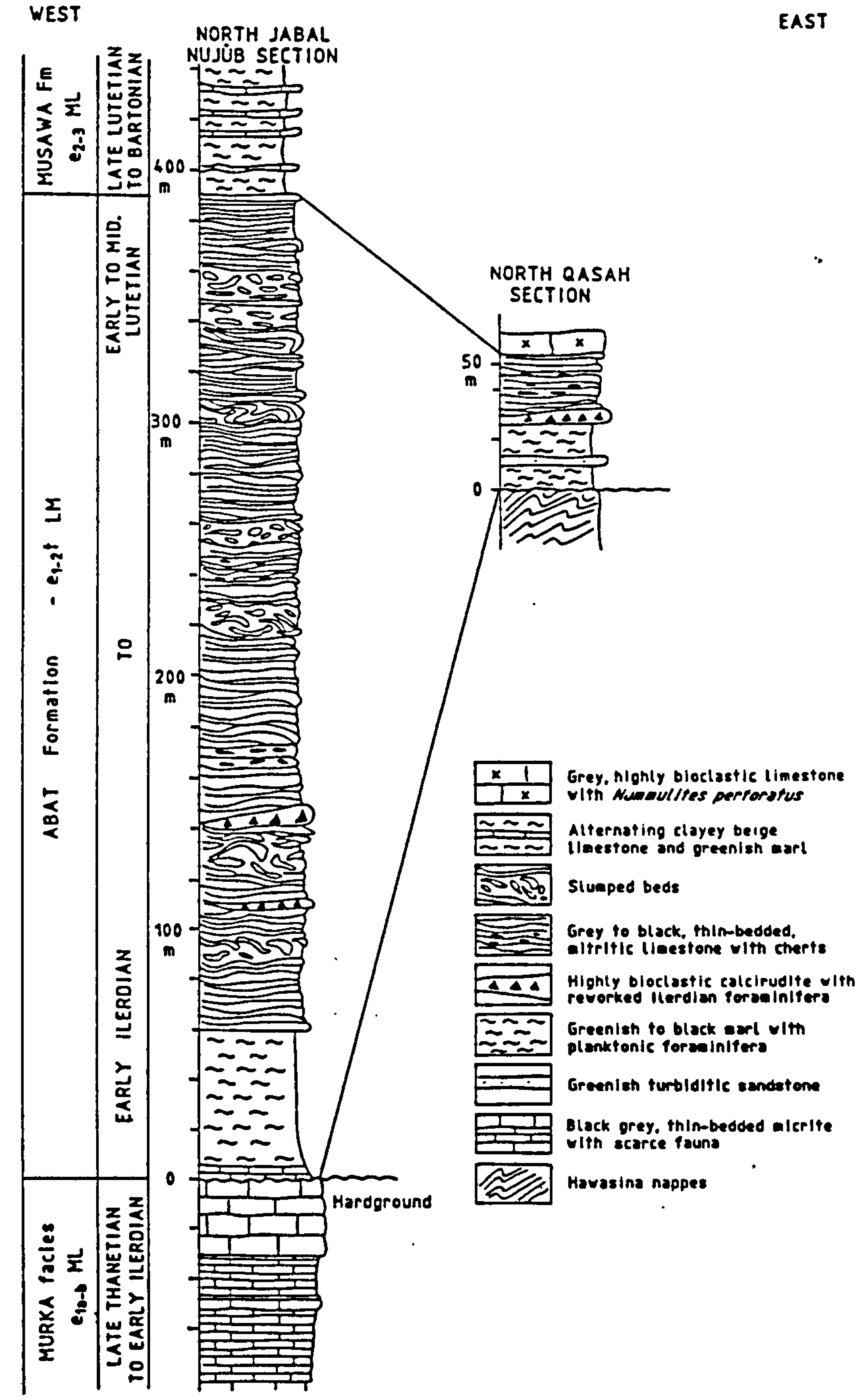



**Fig. 2.6 Lithostratigraphic column for the Abat Formation (after Roger *et al.*, 1991).**

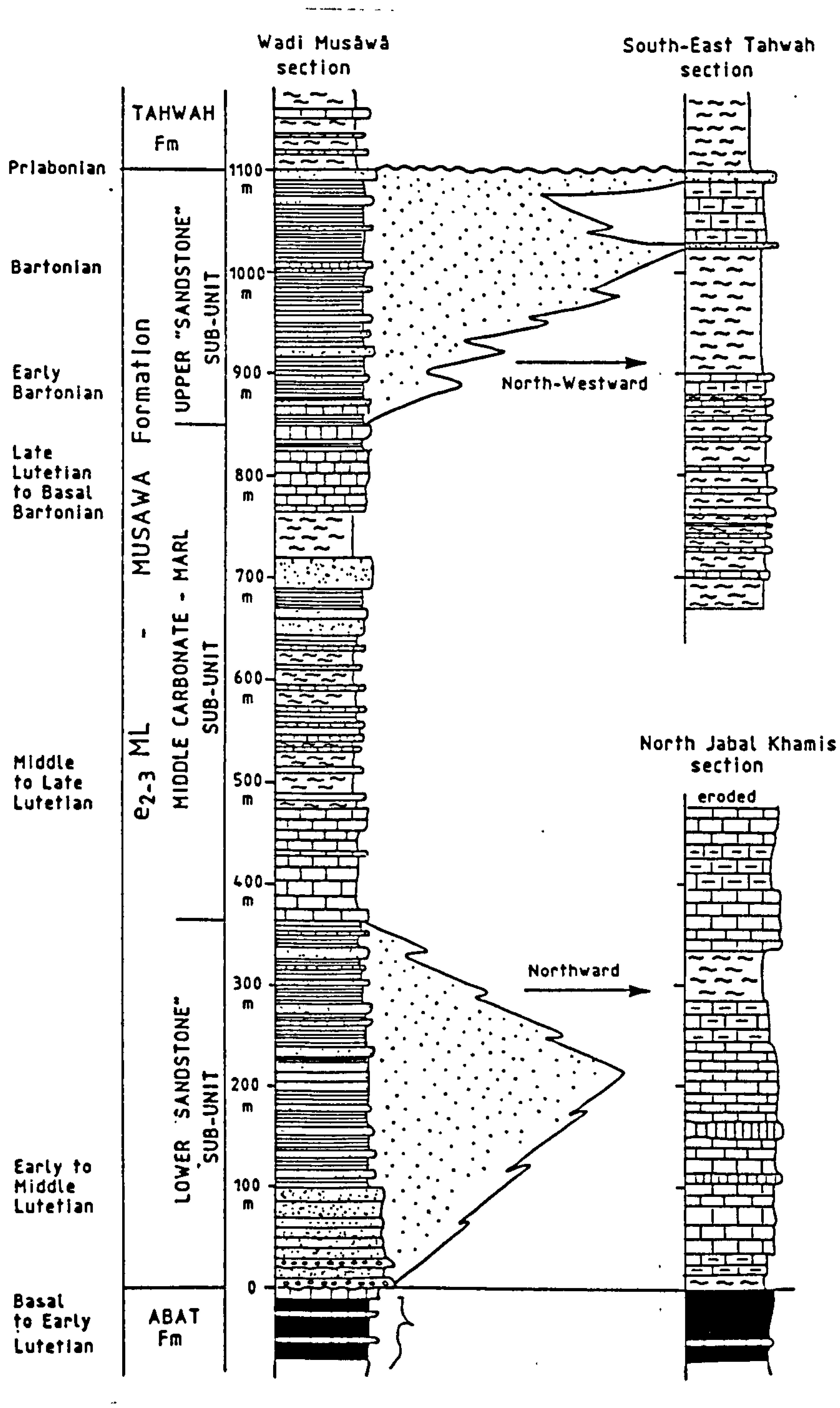



**Fig. 2.7 Lithostratigraphic column for the Musawa Formation (after Roger *et al.*, 1991)**

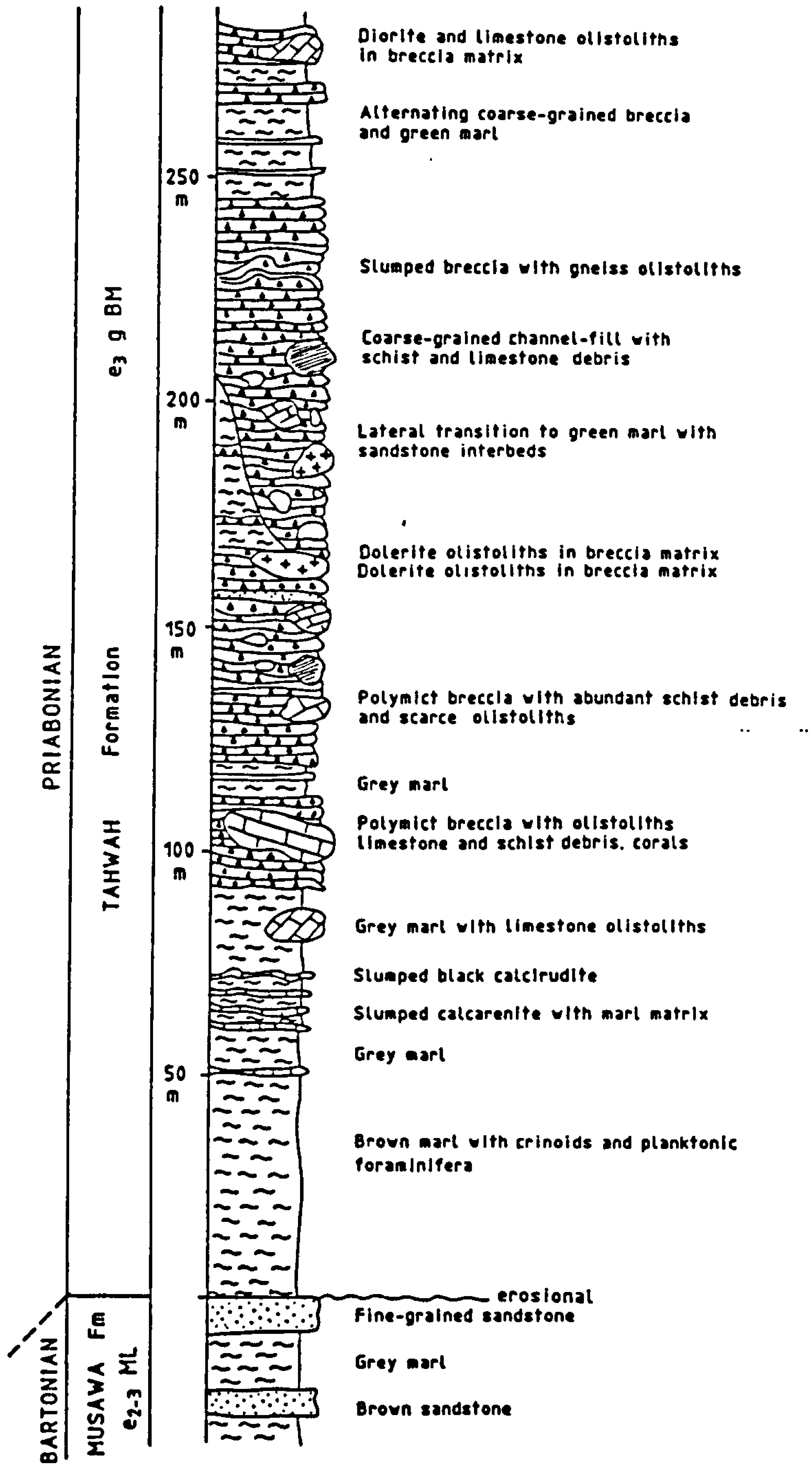



**Fig. 2.8 Lithostratigraphic column for the Tahwah Formation (after Roger *et al.*, 1991)**

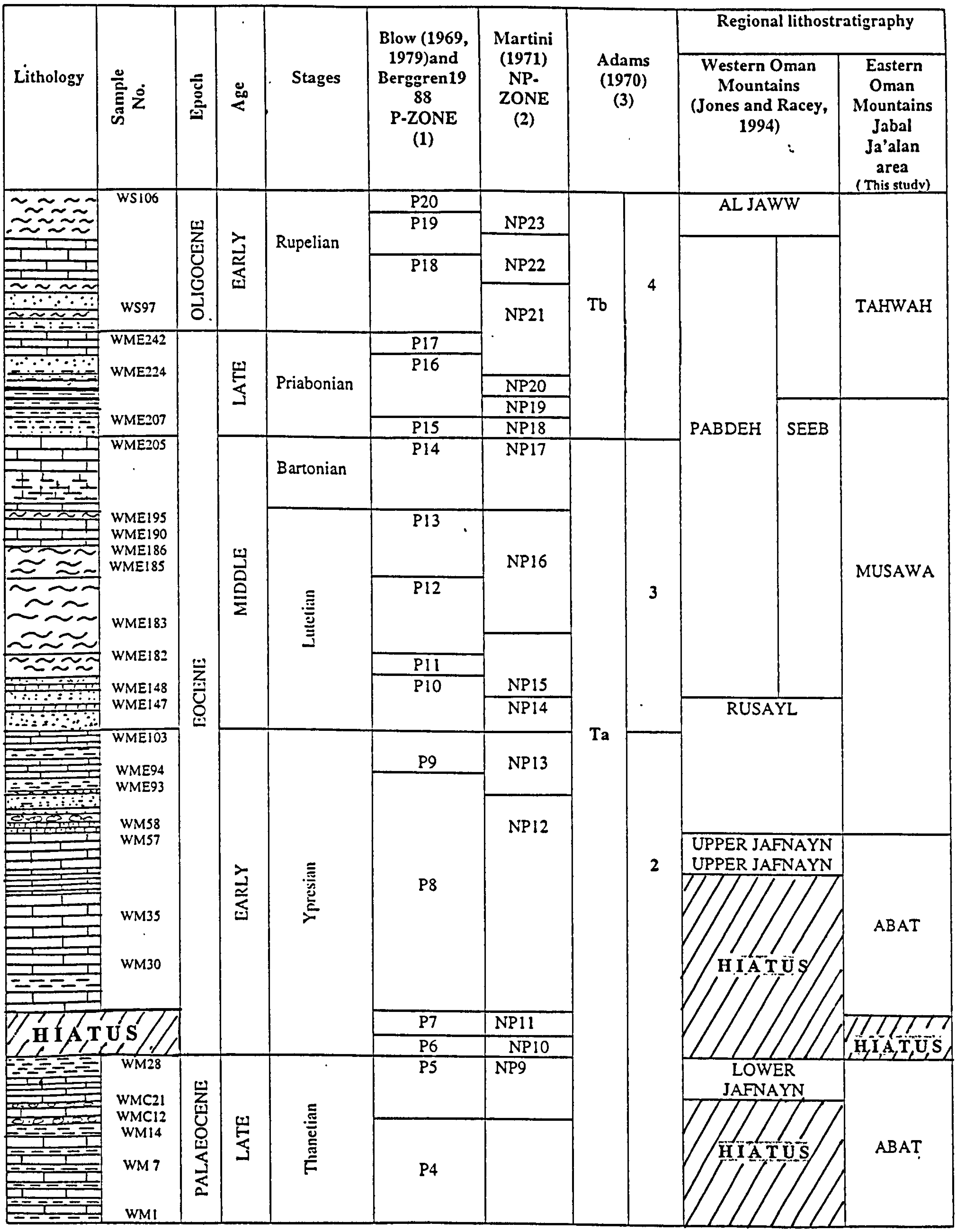



**Fig. 2.9 Summary stratigraphy Eastern Oman Mountains compared with Western Oman Mountains: 1) Planktonic Foraminifera, 2) Calcareous nannoplankton, 3) Larger Foraminifera (modified after Jones and Racey, 1994).**

# *Chapter Three*
# *Lithostratigraphy*

# *Chapter Three*

# LITHOSTRATIGRAPHY

## 3.1 INTRODUCTION

This section outlines the stratigraphic nomenclature applied herein and summarizes the lithology, palaeontology, depositional environment and age for each unit. A brief summary of the sequence stratigraphy of the studied sequence is given at the end of this chapter. Limestone textures are described using the terminology of Dunham (1962) whilst interpretation of environment of deposition is based mainly on faunal assemblages and depositional fabrics as outlined in previous publications including Henson (1950), Adams (1965), Nolan *et al.* (1986), Racey (1988, 1994 and 1995), White (1989) and Roger *et al.* (1991). Planktonic Foraminifera were identified using the Ellis and Messina catalogue 1981, Postuma (1971) and more recent publications (see Chapter Four). Larger Foraminifera (see Chapter Five) such as nummulitids were identified using Racey (1988, 1995), Schaub (1981) and Samanta (1990), whilst White (1989, 1992) and Hottinger (1962) were used for the identification of the alveolinids and Samanta (1985) to identify the discocyclinids.

The Wadi Musawa section is located in the Jabal Ja'alan area, in the Sharqiyah region on the SE edge of the Oman Mountains (Fig. 3.1). The Tertiary sequence differs markedly from the mainly shallow marine carbonate dominated Tertiary sequences of most of Northern Oman in that it comprises a more diverse range of lithologies including deep and shallow marine carbonates, fluvial and marine siliciclastics, coals and palaeosols deposited in a dominantly strike-slip setting (see enclosure Fig. 3.2 and summary sketch of cross-section and field photograph Fig. 3.3).

The studied section comprises three formations, which are defined on the basis of lithology, faunal content and nature of the contacts between them. These formations comprise in ascending stratigraphic order the Abat, Musawa and Tahwah Formations (Fig. 3.3 and Fig. 3.4).

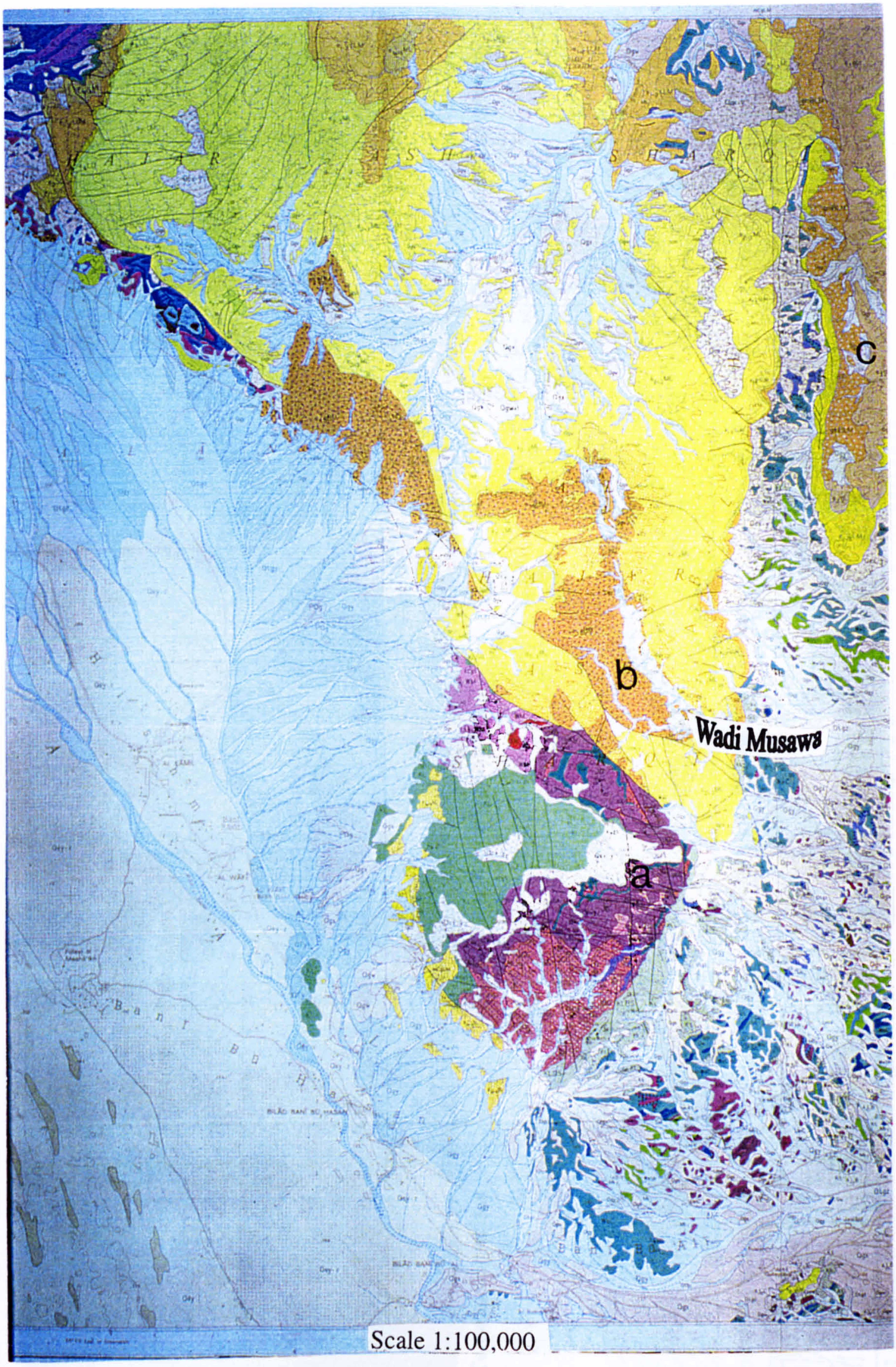



**Fig. 3.1 Geological map of Ja'alan area showing three geological provinces: a) Southeastern b) North Central and c) Northeastern.**

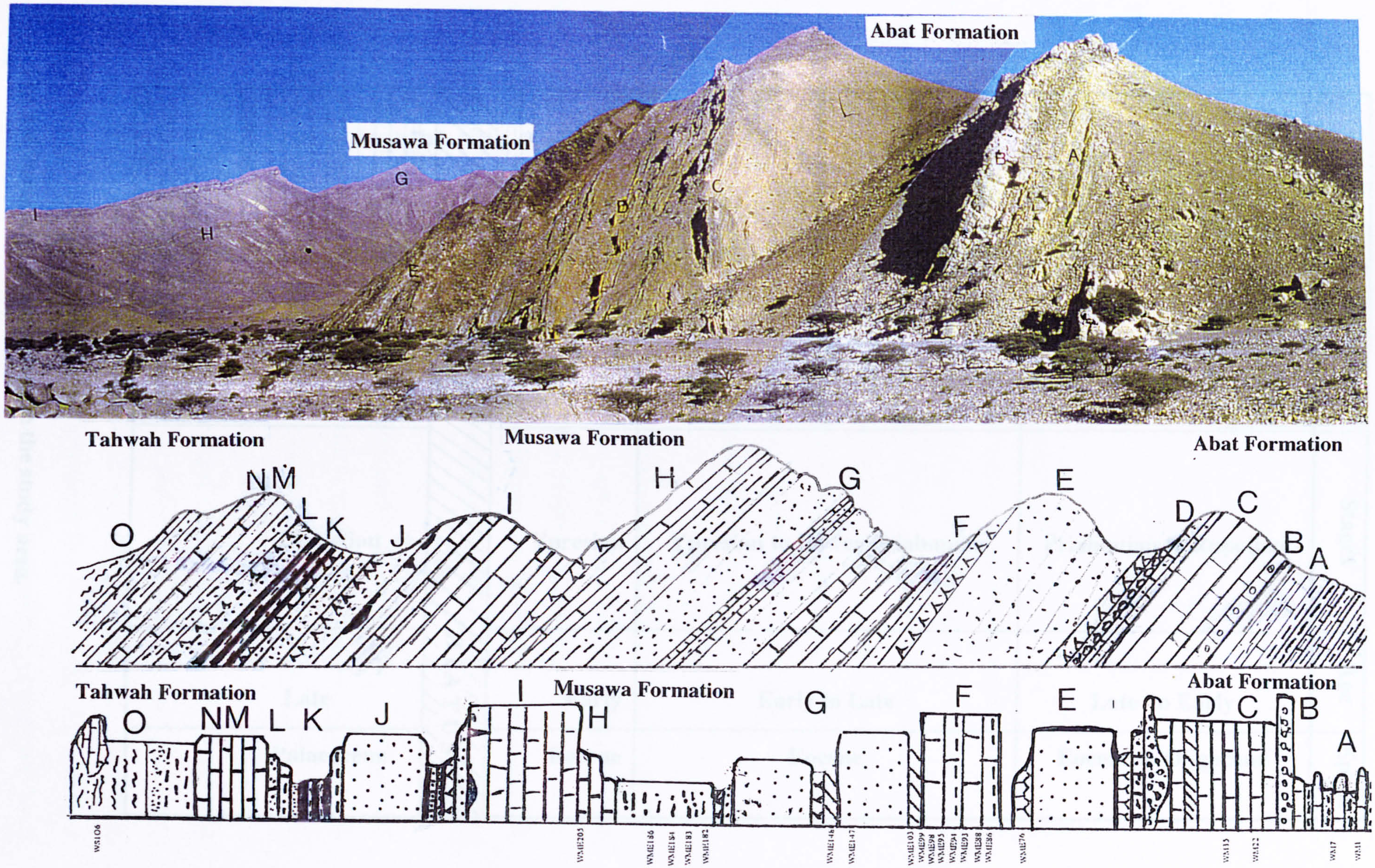



Fig. 3.3 Field photo shows the Abat formation, Musawa Formation and Tahwah Formation, Sketch cross-section through Wadi Musawa and Wadi suq Section and lithostratigraphic column for Wadi Muswa and Wadi Suq section. (not to scale).

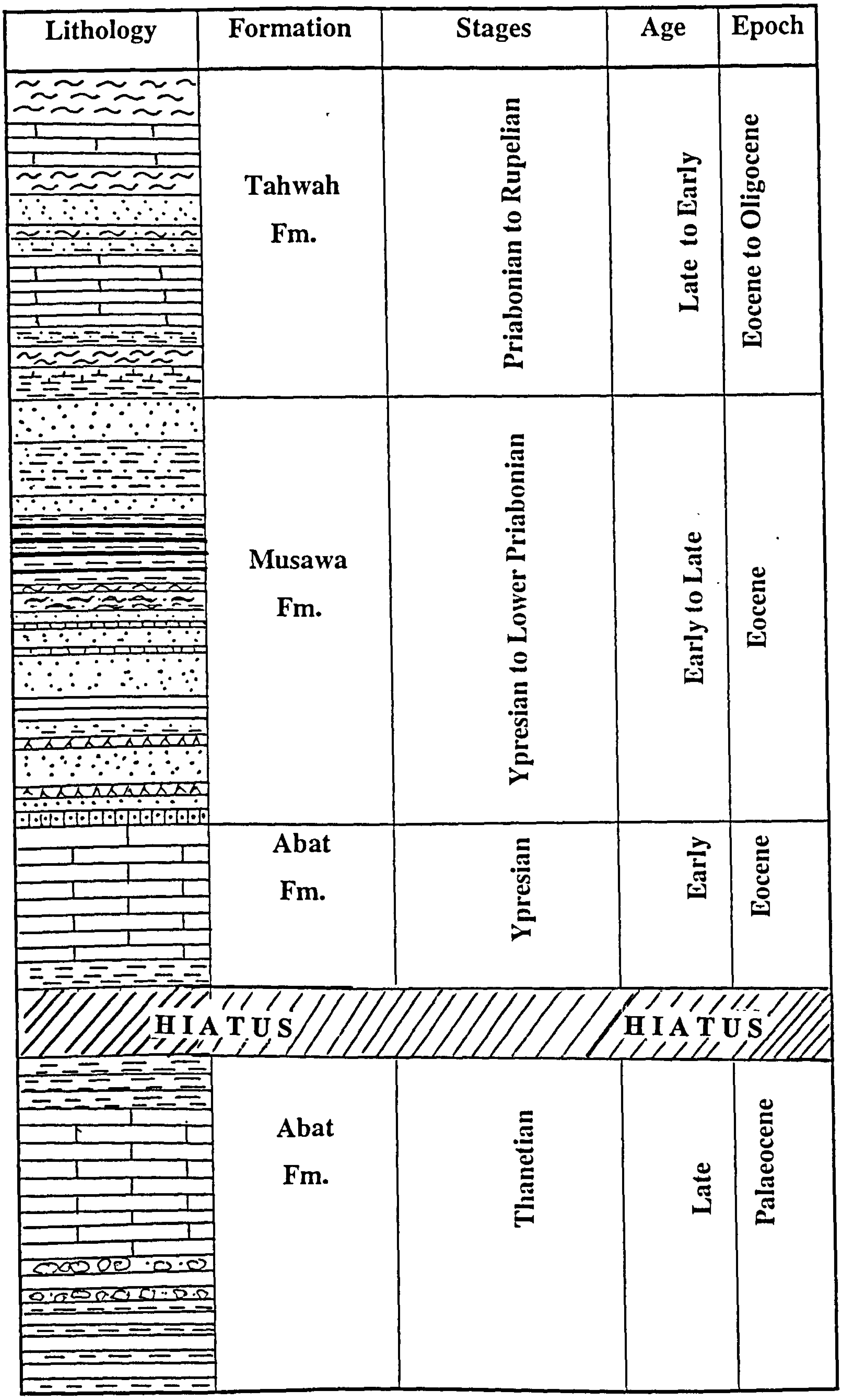



**Fig. 3.4 Summary of formations in the study area.**

Planktonic and larger Foraminifera (matrix-free) occur together in many of these units. Their age ranges are such as to preclude reworking, rather they seen to have been redeposited (pene) contemporaneously due to syndepositional tectonism in the study area throughout most of the Palaeogene. This phenomenon is discussed further elsewhere, in particular in Chapter 7.

## 3.2 Wadi Musawa

### 3.2.1 Abat Formation

*Type-Locality*: Wadi Musawa Lat. 22$^0$ 19' N and Long. 58$^0$ 23'E

This formation begins with thinly interbedded shales and mudstones, which are overlain by planktonic foraminiferal bearing wackestones with interbeds of mudstone and calcarenites. Approximately 9m of the overlying lithology is poorly exposed and passes into resedimented limestones (wackestones to packstones) comprising six cycles. The middle of the formation is characterized by thinly bedded wackestone overlain by shale (13m thick) which pass upwards into an upper unit consisting of limestone, dolostone and, near the top of the formation, palaeosol (see enclosure Fig. 3.2).

The Abat Formation contains planktonic Foraminifera including *Morozovella* and *Subbotina* species especially in the mudstones and shales of its lower part. Typical shelf larger Foraminifera include *Discocyclina, Daviesina, Miscellanea, Nummulites* and *Assilina.* together with small rotaliids, textulariids, calcareous red algae, echinoid plates and corals especially in the limestones of the upper part.

The Formation unconformably overlies Maastrichtian sandstone turbidites and interbedded marls of the Fayah Formation, and is conformably overlain by sandstones of the Musawa Formation with which it interdigitates in its upper part.

Although the contact between the Cretaceous and Tertiary is unexposed (see Fig. 3.3) an unconformity is inferred based on the occurrence of mixed Maastrichtian and Palaeocene planktonic Foraminifera in the lowermost samples. This observation although outside the scope of this thesis does merit further research with a view to identifying the nature of the contact in terms of its microfauna though it is most likely that as noted elsewhere in the Arabian Peninsula, the Lower Palaeocene is absent (Jones and Racey, 1994). I have divided the Abat Formation into four lithostratigraphic units (A-D Fig. 3.5) which are described in more detail below:

| *Lithology* | *Unit* | *Thickness (in metres)* | *Age* |
|---|---|---|---|
| Limestone, calcareous shale, dolomite, sandy limestone, cherty conglomerate and palaeosols | D | 33m | Late Palaeocene to Early Eocene (Early Ypresian) |
| Limestone and shale | C | 16m | Late Palaeocene (Thanetian) |
| Resedimented limestone (Six cycles) | B | 17m | Late Palaeocene (Thanetian) |
| Shale, mudstone and limestone. | A | 24m | Late Palaeocene (Thanetian) |

**Fig. 3.5 Lithostratigraphic units of the Abat Formation.**

**3.2.1.1 UNIT A** *(WM 1 to WM 14).*

***Description*:** This unit begins with a thin layer of shale (3-10cm thick) overlain by 20cm of mudstone followed by 4m of alternating wackestones and shales all of which contain a common and diverse planktonic foraminiferal fauna. These are overlain by 2m of wackestones, which become progressively less siliciclastic- rich upwards (see enclosure Fig. 3.2) and comprise planktonic foraminiferal-bearing wackestone (Pl. 3.2.1.1a).

Planktonic Foraminifera are particularly common in the lower part of the unit and include *Morozovella acuta*, *Morozovella angulata*, *Morozovella velascoensis* and

*Subbotina triloculinoides*. Benthonic Foraminifera are common in the upper part of the unit (with rare planktonic Foraminifera) and include *Discocyclina* sp. (Pl. 3.2.1.1b), *Assilina* sp. (Pl. 3.2.1.1c), *Nodosaria* sp., *Glandulina* sp., *Anomalinoides* sp., *Lenticulina* sp., *Dorothia* sp., *Clavulina* sp., *Ammobaculites* sp., *Cibicides* sp., indeterminate smaller rotaliids and textulariids (Pl. 3.2.1.1d). Solitary corals, echinoid plates and calcareous red algae are also locally present in the upper half of the unit (Pl. 3.2.1.1e).

***Age***: The unit is ascribed a Late Palaeocene (Thanetian) age based on the presence of *Morozovella acuta*, *Morozovella angulata* and *Subbotina triloculinoides* occurring within the *Morozovella acuta* Zone (P4), which is local expression of the standard zone of Blow (1969; 1979) and Berggren *et al.* (1988). The associated larger Foraminifera include *Daviesina iranica* which has been recorded from the Upper Palaeocene of Iran (Rahaghi, 1983) whilst *Daviesina persica*, a species not known above the Palaeocene, has been found within the Upper Palaeocene *Alveolina* (*Glomalveolina*) *primaeva* Zone elsewhere in Oman (White, 1994). The larger Foraminifera thus support the age assigned on the basis of the contained planktonic Foraminifera.

***Thickness***: 18m.

***Environment***: The lower part of this unit consists of interbedded mudstones and shales with a diverse and rich planktonic foraminiferal fauna indicative of a deep, open marine, basinal environment. These are overlain by wackestones and packstones containing larger rotaliids (*Miscellanea*, *Daviesina*, *Discocyclina*, *Assilina*), small rotaliids, red algae, corals and echinoid spines suggesting a shallow marine fairly high energy open marine outer shelf/platform environment.

***Contact***: The unit unconformably overlies the Cretaceous although the lower contact is mainly covered by scree in the study area. However, upon digging a trench below sample WM1 an additional sample containing reworked Maastrichtian planktonic Foraminifera mixed with Palaeocene planktonic Foraminifera was recorded. The top part of the unit although unexposed, shows a continuation of shallow marine carbonates, which lack planktonic Foraminifera and contain common larger Foraminifera. These carbonates are "coarser", being more rudaceous and packstone-grainstone dominated suggesting a continued shallowing upwards from Unit A to Unit B.

### 3.2.1.2 UNIT B *(WMC 12 to WMC 21).*

***Description***: This comprises at least six prominent limestone cycles coarsening upwards (Pl. 3.2.1.2a), each of which varies in grain size and composition from calcirudite to calcarenite to calcilutite (see enclosure Fig. 3.2).

Texturally these cycles comprise packstones/grainstones interbedded with mudstones. They show graded-bedding and have erosive bases with the top of each cycle showing characteristic parallel and more rarely cross-lamination. Karstic weathering indicative of possible palaeokarst was only observed in the uppermost part of the unit (top 10-20cm).

The limestones contain common larger Foraminifera including *Daviesina iranica, Miscellanea primitiva, Lacazinella* sp. (Pl. 3.2.1.2b), *Discocyclina* sp. (Pl. 3.2.1.2c) and *Nummulites* sp. with small benthic forms such as *Cibicides* sp. and miliolids. Calcareous red algal fragments are also present though rare.

***Age***: Upper Palaeocene based on the presence of *Miscellanea primitiva* which is known from the Upper Palaeocene of Iran (Rahaghi, 1983). In Oman, *M. primitiva* was recorded from the Upper Palaeocene *Alveolina primaeva* Zone by White (1989) whilst at Wadi Musawa it is found within the Upper Palaeocene base *of Morozovella velascoensis* Zone (P5), which is equivalent to *Morozovella velascoensis* (P5) of Blow (1969; 1979) and Berggren *et al.*, (1988).

***Thickness***: 17m.

***Environment***: These sediments mainly represent calciturbidite and slope deposits based on their sedimentary structures with bioclasts derived from a shallow marine mid-outer platform (containing common larger rotaliid Foraminifera). Since this unit is interpreted as being deposited in a slope depositional setting the absence of planktonic Foraminifera within this unit may indicate that the basin was not open to deep marine circulation.

***Contacts*:** The lower and upper contacts are unexposed. The lower contact is probably conformable. The nature of the upper contact is less certain, though it appears to represent a gradual deepening into Unit C.

### 3.2.1.3 UNIT C *(WM 21 to WM 28)*

***Description*:** This unit starts with a thin layer of wackestone overlain by mudstone, shale and wackestone which pass upwards into a thicker interval of interbedded mudstones and shales containing planktonic Foraminifera. The wackestone at the base also contains planktonic Foraminifera plus rare miliolids (resedimented) and subrounded, medium grained quartz clasts (see enclosure Fig. 3.2 and Fig. 3.3).

Planktonic Foraminifera include *Morozovella acuta* (Pl. 1, Figs. 4-12), *M. velascoensis* (Pl. 8, Figs. 7-12), *M. occlusa* (Pl. 6, Figs. 7-9) *M.* cf sp. *parva* (Pl. 6, Figs. 10-12). Larger Foraminifera comprise *Nummulites* and *Alveolina* (especially in the upper part of the unit), plus smaller benthic Foraminifera including *Lenticulina, Nodosaria, Glandulina* and *Clavulina*. Ostracods occur locally through the unit.

***Age*:** Late Palaeocene based on the presence of the planktonic Foraminifera *Morozovella acuta, M. occlusa* and *M. velascoensis* indicative of the *Morozovella velascoensis* Zone P5 of Blow (1969; 1979) and Berggren *et al.*, (1988) respectively.

***Thickness*:** 15 m

***Environment*:** Deep at the base with planktonic Foraminifera, passing upwards to shallow marine (mid-platform/shelf) at the top based on the dominance of the larger Foraminifera *Nummulites* and *Alveolina*.

***Contact*:** The base and top of this unit are not exposed. The basal contact is probably gradational with the underlying Unit B whilst the upper contact may also be conformable since the overlying (Unit D) shows a continued shallowing upwards trend.

**3.2.1.4 UNIT D** *(WM 29 to WM 57)*

***Description***: This unit begins with packstone and mudstone separated by a very thin (7cm thick) distinctive silicified mudstone (see enclosure Fig. 3.2 and sample *WM 31a*, Pl. 3.2.1.4a and Pl. 3.2.1.4b) from an overlying limestone (packstone). An unexposed (scree covered) interval about 1.6m thick passes up into a thick massive limestone (packstone, wackestone and mudstone) with two distinctive dolomite layers each Ca 1m thick.

The basal part of the unit comprises 30cm of orange coloured limestone (packstone) containing burrows (large vertical branching burrows cf, *Thalassinoides*). This is overlain by 60cm of poorly consolidated mudstone which is very rich in planktonic *Acarinina, Morozovella,* and larger Foraminifera including *Alveolina, Nummulites* (Pl. 3.2.1.4c), *Discocyclina* and *Operculina musawaensis nov.* The burrows are mainly infilled with Foraminifera from the overlying bed. This passes upwards into 35cm of thinly bedded shale containing *Nummulites* and small rotaliids. The unit becomes more indurated up-section and contains molluscs, burrows, *Nummulites*, corals, gastropods and oysters. The molluscs are often preserved with both valves together as moulds in approximate life-position. The top of the middle part of this unit is characterized by a 1-5m thick bed rich in *Assilina* (95%) and *Nummulites* (5%) (Pl. 3.2.1.4d).

Lithoclasts and Foraminifera are less abundant in the uppermost part of the unit where clasts of grey chert (weathering orange and up to about 80mm across) are common together with rare silicified burrows. Bivalves (often disarticulated) are also common in the uppermost part of the unit.

Larger Foraminifera comprise *Alveolina, Nummulites honogoensis, N. globulus, Discocyclina, Assilina* ex. gr. *exponens* (Pl. 3.2.1.4e), *Somalina* sp. (Pl. 3,2,1.4f), *Actinocyclina* (Pl. 3.2.1.4g), *Operculina musawaensis nov.* (Pl.3.2.4h), *Ranikothalia.*

(Pl. 3.2.1.4i) together with smaller rotaliids, miliolids, textulariids and rare dasycladacean algae (Pl. 3.2.1.4j). Planktonic Foraminifera include *Acarinina esnaensis, A. soldadoensis* and *Morozovella aragonensis* and *Subbotina quadrata.* Other fossil fragments present include gastropods and rare brachiopods.

***Age***: Early Eocene based on the occurrence of *Morozovella marginodentata, M. aragonensis, Acarinina esnaensis,* and *A. soldadoensis* with associated larger Foraminifera including typical Early Eocene taxa including *Nummulites globulus.* Although *Somalina* is typically considered to be Middle Eocene in age White (1989) found *Somalina hottingeri* in late Early Eocene rocks from Northern Oman. This unit represents the *Morozovella aragonensis* Zone P8 of Blow (1969; 1979) and Berggren *et al.* (1988).

***Thickness***: 33m.

***Environment***: The unit shows a gradual change from deep marine basinal facies rich in planktonic Foraminifera in its lower part into shallow marine mid-outer shelf limestones with *Nummulites, Assilina* and *Discocyclina* plus rare dasycladacean green algae (fragments) in its upper part and is capped by unfossiliferous shales of probable fluvial origin and palaeosols. Ostracods from samples WM34-WM40 include *Bairdia* and *Cytherella,* which occur from near shore to circalittoral environment and thus do not indicate any particular shelf environment. The presence of *Phalcocythere* and *Xestoleberis* in samples WM37 and WM40 suggests shallow marine environments (Dr. M. Keen pers. com. 1998).

***Contact***: Basal contact gradational whilst upper contact grades into fluvial sandstones.

### 3.2.2 Musawa Formation

***Locality***: Wadi Musawa Section Lat. 22° 19' 11"N and Long58° 23' 10"E

The Musawa Formation mainly comprises three dominantly fluvial units (mainly sandstones) which are ferruginous at the base, contain coal seams towards the top and are separated by a carbonate dominated unit and a coal/shale dominated unit. Rare coal seams, palaeosols and thin limestones, mudstones, sandstone, siltstones, and shales occur throughout the formation. I have divided the Musawa Formation into eight units (E-L) as outlined in (Fig. 3.6):-

| ***Environment*** | ***Lithology*** | ***Unit*** | ***Thickness (in meter)*** | ***Age*** |
|---|---|---|---|---|
| | Fine sandstone and siltstone | L | 26 | Late Eocene (Priabonian) |
| Coal 1 | Coal seams, sandstone, siltstone and shale | K | 63 | Late Eocene |
| Fluvial 3 | Sandstone, siltstone, shale and palaeosol | J | 29.5 | Middle to late Eocene |
| Carbonate 3 | Wackestone, packstone and shale | I | 48 | Middle Eocene (Bartonian) |
| Carbonate 2 | Marl, limestone (packstone and wackestone) with hummocky stratification | H | 81 | Middle Eocene (Late Lutetian) |
| Fluvial 2 | Palaeosols, siltstone and sandstone | G | 557 | Middle Eocene (Lutetian) |
| Carbonate 1 | Limestone and shale/mudstone | F | 67 | Early Eocene to M. Eocene |
| Fluvial 1 | Sandy limestone, sandstone, palaeosol and sandy shale | E | 136 | Early Eocene |

**Fig. 3.6 Lithostratigraphic units of the Musawa Formation.**

**3.2.2.1 UNIT E** *(WM 58 to WME 84)*

***Description***: This unit starts with a lower part comprising 80cm of calcirudite overlain by 4.5m of sandy limestone and 16m of conglomerate and palaeosols with thin sandstone interbeds.

The middle part of the unit comprises a thick massive rusty red, well-sorted channeled sandstone dominated by angular to subrounded coarse quartz grains. The base of the middle part of the unit comprises mainly massive rarely cross-bedded very coarse sandstone to angular conglomerate with a maximum clast size of 210mm and an average grain size of 60mm and includes lenses of sandstone containing molluscs. The upper half of the middle part of the unit comprises decimeter scale inter-bedded fine to medium grained sandstones and shales overlain by 85cm of microconglomerate which pass upwards into coarse sandstone with occasional pockets of granular conglomerate lags showing erosive bases.

The upper part of the unit consists of a 17.30m thick palaeosol dominated interval capped by very coarse-grained sandstone. Another thick layer of sandstone with a distinctive thin layer of sandy shale at its base overlies this bed. This sandstone fines upwards and is rippled towards its top (see enclosure Fig. 3.2).

The upper part of this unit is characterized by a thick medium to very coarse-grained sandstone capped by mottled palaeosols with common rootlets, abundant gypsum (secondary) and very thin interbeds of fine-grained sandstone (Pl. 3.2.2.1a).

The lower part of the unit contains reworked larger Foraminifera including *Assilina, Nummulites, Discocyclina,* plus miliolids and *Alveolina* (Pl. 3.2.2.1b).

The middle part of the unit contains a distinctive fauna of reworked Radiolaria (including Jurassic forms derived from the Hawasina Group) and charophytes (Cretaceous forms) in thin shales/mudstones and reworked (often silicified) larger Foraminifera including *Alveolina, Assilina, Discocyclina, Nummulites, Somalina.* (Pl. 3.2.2.1c), small rotaliids and miliolids (Pl. 3.2.2.1d) in the sandstones.

The upper part of the unit is characterized by palaeosols containing reworked planktonic Foraminifera including *Morozovella caucasica, M. quadrata* and larger Foraminifera including *Nummulites, Operculina* and *Discocyclina* plus ostracods, Mesozoic Radiolaria and charophytes.

***Age***: A maximum Early Eocene (early Ypresian) age is inferred based on the presence of the reworked Planktonic Foraminifera *Morozovella caucasica, M. centralis, Subbotina quadrata* and *Subbotina triangularis.* These species occur within the *Morozovella aragonensis* Zone P8 of Blow (1969; 1979) and Berggren *et al.* (1988).

***Thickness***: 136m.

***Environment***: A mixture of alternating fairly proximal continental fluvial channel sandstones with subordinate flood plain deposits and palaeosols with reworked planktonic Foraminifera, larger Foraminifera, ostracods and Radiolaria.

***Contact***: The basal contact represents an angular unconformity whilst the upper contact is not exposed but probably represents an unconformity since the environment changes dramatically from fluvial to carbonate dominated.

**3.2.2.2 UNIT F (WME 85 to WME 112)**

***Description***: The unit begins with 30cm of lenticular interbedded mudstones and wackestones overlain by interbedded shales, mudstones and wackestones making up the lower third of the unit.

The middle part of the unit, about 27m thick comprises massive limestone (wackestone) containing planktonic Foraminifera, ostracods, branching bryozoans (Pl. 3.2.2.2a) and very rare reworked Radiolaria.

The upper part of the unit consists of a thin layer of shale overlain by grey packstones followed by alternating mudstones and wackestones. The top of the upper part is unfossiliferous at Wadi Musawa though along strike it is highly fossiliferous containing bivalves and gastropods (see enclosure Fig. 3.2).

This unit contains planktonic Foraminifera including *Morozovella abundocamerata, M. aequa, M. aragonensis, M. caucasica, M. crater, M. formosa formosa, M. gracilis, M. marginodentata, A. pentacamerata, Subbotina sp.* and *Hastigerina* sp. The larger

Foraminifera include *Coskinolina balsillei, Dictyoconus egyptiensis, Nummulites atacicus, Linderina* sp., *Discocyclina* sp. and miliolids (Pl. 3.2.2.2b) and occur in massive limestones forming the central part of the unit. Macrofauna includes bivalves, gastropods, echinoid spines (Pl. 3.2.2.2c) and solitary corals. Septarian nodules are common throughout the unit.

*Age*: Lower Eocene (Upper Ypresian) based on planktonic and larger foraminiferal faunas. Planktonic Foraminifera include *Morozovella caucasica, M. abundocamerata, M. formosa formosa, M. gracilis, M. aragonensis, M. crater, M. aequa, M. subbotinae, Acarinina pentacamerata, Globigerinatheka subconglobata subconglobata. Nummulites atacicus* was previously recorded from the Late Ilerdian of Oman by Racey (1995). This unit ranges from the *Morozovella aragonensis* Zone (P8) to *Acarinina pentacamerata* Zone (P9), of Blow (1969; 1979) and Berggren *et al.* (1988), suggesting that *N.* cf. *atacicus* may be reworked.

*Linderina* is generally taken as indicative of the Middle Eocene whilst the large agglutinating forms *Coskinolina balsillei* and *Dictyoconus egyptiensis* are typical of the Early Eocene.

***Thickness***: 67 m

***Environment***: Deep marine, shallowing upwards. The lower part of the unit is rich in mudstone/shale with a rich and moderately diverse planktonic foraminiferal assemblage indicating a deep open marine environment. The middle part of the unit contains common *Nummulites* and *Discocyclina.* The Upper part of the unit contains miliolids, molluscs, corals echinoid spines and ostracods indicating a partially restricted shallow marine environment.

**Contact:** Upper and lower contacts are unexposed. Lower contact is probably an unconformity with planktonic Foraminifera-bearing limestones and shales directly overlying palaeosols of Unit E. The upper contact is not exposed, but again probably represents an unconformity as it is overlain by a second fluvial and palaeosol dominated package (Unit G).

### 3.2.2.3 UNIT G *(WME 113 to WME 180).*

***Description***: A 557m thick unit mainly of medium grained sandstone (Pl. 3.2.2.3a), which is often channelised, cross-bedded and shows ripple marks and siltstones with large intervals unexposed (inferred palaeosols). The unit begins with 11.5m of palaeosol overlain by about 100m of siltstone and sandstone with thin interbeds of limestone which pass up into a second 16.3m thick palaeosol with a 20cm thick orange coloured wackestone in its middle part. The intervals above and below the palaeosol are covered by scree and could not therefore be examined (see enclosure Fig. 3.2).

A 12m thick reddish brown sandstone with poorly developed palaeosols (Pl. 3.2.2.3b) characterizes the base of this interval. Sandstones with resedimented fossil lags overlie these palaeosols with the remainder of the interval comprising interbedded mudstones (WME115 WME116), siltstones (WME117) and sandstones with thin (30-40cm thick) limestones in the lower part and limestones up to 5m thick in the upper part.

The palaeosol dominated interval is overlain by about 415m of sandstone and siltstone with thin limestone (ankerite) horizons. A large part of this unit is unexposed or may be represented by softer, weathering palaeosols (see enclosure Fig. 3.2).

The middle part (i.e. WME131 to WME163) of the unit comprises interbedded siltstone with gypsum (secondary) and thin beds of oyster rudstone. Above the oyster band the lithology changes upwards from white and purple siltstones with a 1m thick oyster bed rich in reworked Radiolaria (WME149-WME150) to rudstone (WME160) at the top of the middle part of the unit. Two carbonate horizons rich in ankerite (WME147 and WME148) with planktonic and larger Foraminifera are present within this unit and are under and overlain by a thin more clastic interval containing common oysters and this characterises the middle part of the unit.

The upper part of the unit (WME164-WME180) consists of alternating well-sorted coarse to fine-grained sandstones which often show graded bedding and have channelised bases.

Ostracods, Radiolaria (Mesozoic) and reworked larger Foraminifera from the underlying unit including *Alveolina* sp. and small rotaliids (Pl. 3.2.2.3c) occur at the base of the unit. The middle part of the unit contains a planktonic foraminiferal fauna including *Truncorotaloides topilensis, Globigerinatheka euganea Morozovella edgari* and *Turborotalia blowcentralis* and a diverse associated larger foraminiferal fauna including *Nummulites maculatus N. discorbinus, Alveolina, Asterocyclina, Discocyclina, Operculina, Rotalia, Gypsina* and *Linderina.* Other Foraminifera include *Neorotalia omanensis nov., Pararotalia, Lenticulina, Elphidium, Glandulina, Spirolina.* and miliolids. Ostracods and reworked Radiolaria also occur sporadically throughout this unit. All the above faunas occur in the middle part of the unit (i.e in samples WME 147 and WME 148).

***Age*:** Middle Eocene (Lutetian) based on the presence of *Truncorotaloides topilensis. Nummulites maculatus* was recorded by Racey (1995) from Oman within the upper part of the Middle Eocene. Samanta (1981) assigned *N. maculatus* to the *Truncorotaloides rohri* Zone, upper Middle Eocene in India. In Wadi Musawa *N. maculatus* was found within the *Truncorotaloides topilensis/Morozovella edgari* Zone. This unit represents local expression of the standard zone P10 of Blow (1969, 1979) and Berggren *et al.* (1988).

***Thickness*:** 557m.

***Environment*:** Fluvial channels and overbank deposits with palaeosols and two distinct ankeritic carbonates yielding planktonic and larger Foraminifera which are assumed to represent flooding surfaces. Other carbonate (ankerite) rich horizons which are unfossiliferous but with oysters immediately above and below them are assumed to represent more minor flooding surfaces.

***Contact*:** The base of this unit probably rests unconformably on underlying shallow marine carbonates of Unit F. The top of this fluvial dominated package is unconformably overlain by marls containing planktonic forams and ostracods.

### 3.2.2.4 UNIT H (*WME 181 to 191*)

***Description***: The unit comprises a thick layer of marl (81m) overlain by a thin interval (2-3m) nodular grey limestones interbedded with marls. A 3m thick hummocky cross-stratified limestone caps this unit. The marly layers contain abundant conical-shaped solitary corals and larger Foraminifera including *Alveolina, Discocyclina dispansa, Nummulites, Neorotalia omanensis* nov., miliolids and ostracods (see enclosure Fig. 3.2).

The hummocky cross-stratified limestone contains molluscs including *Bicorbula*, lucinids and naticids (Pl. 24, Figs. 3-15).

Planktonic Foraminifera including *Morozovella edgari, M. bolivariana, Truncorotaloides libyaensis* and *Globigerina* were found in the middle of the unit. The larger Foraminifera include *Nummulites maculatus, Nummulites* cf. *schaubi, Discocyclina dispansa, Assilina, Alveolina, Neorotalia omanensis* nov., *Operculina, Linderina, Nonionella, Pararotalia* plus miliolids and rare ostracods. Burrows and macrofossils including gastropods (i.e. *Natica*), oysters and corals also occur throughout.

***Age***: Middle Eocene (Upper Lutetian) based on the presence of the planktonic Foraminifera *Truncorotaloides libyaensis, Truncorotaloides topilensis, Morozovella bolivariana* and *Globigerinatheka barri, Globigerinatheka curryi* and *Globigerinatheka* sp. B. *Nummulites schaubi* and *N. maculatus* were recorded by Racey (1995) from the Middle Eocene (Lower and Middle Lutetian) of Oman. The unit ranges within the *Truncorotaloides topilensis* Zone to *Truncorotaloides libyaensis/Morozovella bolivariana* Zone representing the local expression of the standard zones *Globigerinatheka subconglobata subconglobata* Zone to *Orbulinoides beckmanni* Zone P13 of Blow (1969, 1979) and Berggren *et al.* (1988).

***Thickness***: 81m

***Environment*:** Outer shelf environment. Deeper at the base of the unit based on the higher abundance and diversity of planktonic Foraminifera, then shallowing upwards. The top of the unit is characterized by a low intertidal to subtidal molluscan assemblage (Dr. Noel Morris, Natural History Museum, London, Pers. Comm. 1998).

***Contact*:** The lower contact is sharp and rests unconformably on fluvial-dominated clastics whilst the upper contact is gradational and comprises interbedded thin limestones and marls.

**3.2.2.5 UNIT I** *(WME 192 TO WME 206)*

***Description*:** This unit begins with nodular grey wackestones interbedded with marls overlain by 6.40m of unexposed section, then alternating wackestones and marls. The middle part of the unit is dominated by wackestones with an interval of marls at the base and is capped by hummocky cross-stratified wackestones. The upper part mainly comprises massive rudstones (see enclosure Fig. 3.2).

The lower part of the unit contains *Nummulites* (Pl. 3.2.2.5a), small rotaliids and miliolids (Pl. 3.2.2.5b) with planktonic Foraminifera first appearing in the middle of the unit (sample WME197). The middle part contains ostracods and reworked Jurassic-Cretaceous Radiolaria and charophytes.

The upper part of the unit mainly comprises macrofossils including the bivalves *Bicorbula*, Lucinids (*Anodontia*) and gastropods of the Family Cerethioidea (including *Nodifamus* and *Exechocursus*).

*Age*: Upper Middle Eocene (Bartonian) based on the presence of *Truncorotaloides libyaensis* and *T. topilensis*. *Truncorotaloides libyaensis* has been recorded by El-Khoudary (1977) from the Middle Eocene of the northern Jabal Al Akhdar, Libya. Here it occurs within the *Truncorotaloides libyaensis/Morozovella bolivariana* Zone and *Truncorotaloides libyaensis* Zone local expression of the standard zones P13-P14) of Blow (1969; 1979) and Berggren *et al.* (1988). Larger Foraminifera, including *Nummulites maculatus,* confirm this age whilst the bivalves and gastropods are also typical of the Middle Eocene (pers. comm., Dr. Noel Morris Natural History Museum, London 1998).

***Thickness***: 48mm.

***Environment***: Deep open marine (with planktonic Foraminifera) to outer shelf (with larger Foraminifera including *Nummulites* and *Operculina*). Bivalves and gastropods from the upper part of the unit indicate a low intertidal to subtidal environment (pers. comm., Dr. Noel Morris, Natural History Museum, London, 1998).

***Contact***: Disconformity at the base and unconformity at the top. The upper contact is sharp and is marked by a sudden change from shallow marine carbonates to siliciclastic fluvial dominated sediments.

**3.2.2.6 UNIT J** *(WME 207-WME 215)*

***Description***: This unit comprises interbedded sandstones, siltstones, shales and palaeosols. The lower part consists of thin cherty conglomerate overlain by a thin interval of interbedded sandstone, siltstone and shale (see enclosure Fig. 3.2).

The middle part comprises grey to purple siltstones overlain by brown fine-grained cross-bedding sandstones (Pl. 3.2.2.6b). The upper part begins with shale overlain by palaeosols containing roots and other plant remains.

The lower part contains miliolids (Pl. 3.2.2.6a) and macrofossils including the bivalves *Bicorbula*, lucinids (*Anodontia*) and the gastropods of the Family Cerethioidea (including *Nodifamus* and *Exechocursus*). The middle part contains the Foraminifera *Rotalia* and reworked Mesozoic Radiolaria in the sandstone interval, whilst the upper part contains only reworked Radiolaria.

*Age*: Middle to Upper Eocene (Upper Bartonian to Priabonian ?) based on the age of the underlying unit (Upper Bartonian) and overlying unit (Priabonian). There are no age-diagnostic fossils within the unit.

***Thickness***: 29.5m.

***Environment***: Shallow, fairly restricted marine inner-shelf with miliolids and molluscs in the lower part becoming fluvial-dominated with rootleted horizons towards the top.

***Contact***: Base of the unit rests unconformably on the underlying Unit I, whilst the upper contact is represented by a sharp unconformity.

### 3.2.2.7 UNIT K *(WME 216 to WME 219N)*

This unit is about 63m thick and directly overlies the palaeosol at the top of Unit J. The unit contains twelve coal seams two of which separate it from the underlying and overlying units. The coal seams vary in thickness from about 3m to 20cm and are thickest at the base of the unit. The coals are interbedded with sandstones, siltstones and shales. The shale beds contain bivalves, bryozoans, gastropods and reworked Radiolaria (see enclosure Fig. 3.2).

The first coal seam (3m thick) is overlain by sandstone containing gastropods and reworked Jurassic and Cretaceous Radiolaria. The second coal seam is followed by a third seam with a layer of gypsum. Between the third to sixth coal seams thin intervals of siltstone and shale occur. The middle part of this unit is dominated by five coal seams interbedded with shales and thin very resistive, very fine grained sandstones. The upper part of the unit is mainly unexposed but is distinctly sandier comprising sandstone and thin siltstone beds. The top of the unit is capped by a meter of coal (Pl. 3.2.2.7a).

***Age***: ?Upper Eocene based on the spinose corals including *Stylocoenia ja'alanensis* and button corals (Rosen *et al.*, in prep.). Palynological samples of the shales and coals examined by Dr. J. G. Goodall (Santos) were found to be barren of palynomorphs and yielded only varying amounts of vitrinite and inertinite.

***Thickness***: 63m.

***Environment***: Estuarine with coals. The macrofossils including gastropods, bivalves and rounded corals suggest locally, slightly deeper marine environments but still within the photic Zone (Dr. Noel Morris Natural History Museum, London, pers. comm.1998).

***Contact***: Unconformity at the base and top of the unit.

**3.2.3.1 UNIT L** *(WME 220 to WME 223)*

***Description***: This unfossiliferous unit immediately overlies the coals of the underlying unit and comprises 8m of orange/grey massive fine-grained sandstone overlain by 11m of pink siltstone and capped by 7m of fine to medium-grained sandstone (see enclosure Fig. 3.2). The sandstones show graded bedding while the siltstones display finely developed parallel lamination. No fossils or signs of bioturbation were observed in this unit.

***Age***: Upper Eocene based on the ages of the underlying and overlying units.

***Thickness***: 26m.

***Environment***: Unfossiliferous generally poorly exposed, interpreted as of probable fluvial (floodplain) origin.

***Contact***: Sharp unconformity at the base representing a major break. The upper contact shows a marked change from siliciclastic- to carbonate- dominated sedimentation.

***3.2.3 Tahwah Formation***

***Locality***: Wadi Musawa Section Lat. 22° 19' 11" N and Long. 58° 23' 13" E, and at Wadi Suq Section Lat. 22° 19' 10" N and Long. 58° 23' 12" E.

This formation unconformably overlies the Musawa Formation. The lower part comprises shales/marls interbedded with very thin (20cm thick) layers of hard limestone (WME230). The middle part of the formation comprises siltstones and limestones. The upper part of the formation (exposed at Wadi Suq) comprises poorly bedded siltstones and mudstones. The formation varies in age from Upper Eocene to Oligocene at Wadi Musawa and into the Early Miocene at the top of Wadi Suq. The Tahwah Formation is subdivided herein into three units (M-O) based on lithology and palaeontology as outlined below:-

| *Lithology* | *Unit* | *Thickness (in metres)* | *Age* |
|---|---|---|---|
| Mudstone and siltstone | O | 114.5 | Early Oligocene (Rupelian) |
| Limestone (packstones and wackestones) | N | 33 | Late Eocene (Late Priabonian) |
| Shale, marl, siltstone and packstone and wackestone | M | 56 | Late Eocene (Priabonian) |

**Fig. 3.7 Lithostratigraphic units of the Tahwah Formation.**

**3.2.3.2 UNIT M** *(WME 224 to WME 236)*

This 56m thick unit comprises shales, marls, siltstones and thin wackestones and packstones. The lower part of the unit comprises approximately 16m of shales and contains larger Foraminifera (including *Nummulites* and *Dictyoconus egyptensis*) and planktonic Foraminifera (globigerinids), plus ostracods and reworked Mesozoic Radiolaria (see enclosure Fig. 3.2).

The middle part consists of 14.5m of marl with thin wackestones and packstones and contains planktonic Foraminifera corals (including the distinctive, spinose *Stylocoenia ja'alanesis* plus button corals) plus *Nummulites* and ostracods (Pl. 3.2.3.2a).

The upper part comprises 17m of siltstone dominated by small *Nummulites* (Pl. 3.2.3.2b), planktonic Foraminifera and ostracods. *Nummulites* is often well-sorted (smaller sizes dominating) and abraded.

***Age:*** Late Eocene (Middle to Late Priabonian) on the basis of the occurrence of

*Nummulites striatus*. This species has been recorded from the Priabonian of Northern Oman within the *N. fabianii* Zone by Racey (1995). At Wadi Musawa *N. striatus* occurs in association with *Gypsina globulus*.

***Thickness*:** 56m.

***Environment*:** Deep marine (?slope) based on the presence of common planktonic Foraminifera of the *Globigerina linaperta* group with common intervals of resedimented *Nummulites*. The button corals present are typical of deeper water (slope) type environments (Dr. B. Rosen, pers. comm. 1997).

***Contact*:** Erosional at the base and disconformity at the top.

**3.2.3.3 UNIT N** *(WME 237 to WME 242)*

***Description*:** This unit is about 33m thick and comprise two thick beds of limestone (packstone-wackestone) (see enclosure Fig. 3.2) with a mainly unexposed intervening interval (?marl and shale) (see enclosure Fig. 3.2).

Larger Foraminifera include *Nummulites striatus* and *Discocyclina javana*, *Amphistigina*. (Pl. 3.2.3.3a) and *Spiroclypeus*. (Pl. 3.2.3.3b) plus echinoids (Pl. 3.2.3.3c) corals, gastropods and ostracods. Planktonic Foraminifera (Pl. 3.2.3.3d) include representatives of the *Globigerina linaperta* group (Pl. 17, figs. 1-12 and Pl. 18, figs. 1-6).

***Age***: Upper Eocene (Priabonian) based on the presence of *Nummulites striatus* and *Discocyclina javana*. *Spiroclypeus* is generally considered to range no older than Upper Eocene.

***Thickness***: 33m.

***Environment***: Outer shelf based on the larger foramininfera present (i.e. dominance of larger rotaliids) and planktonic Foraminifera.

***Contact***: Disconformity at base and top.

## 3.3 *Wadi Suq*

### 3.3.1 *Tahwah Formation*

#### 3.3.1.1 UNIT O (WS 97 to WS 107)

***Description***: This unit outcrops only at Wadi Suq and begins with poorly bedded siltstones to mudstones overlain by inter-bedded coarse sandstones, which are bioturbated and rich in oysters. Irregular veins of anhydrite, lenses of green mudstone and bioclastic material together with colonial corals occur throughout as debris flows (Fig. 3.8).

The middle of the unit is characterized by intensively bioturbated medium-grained calcareous sandstones and limestones with *Nummulites* and oysters. The unit is often scoracious to cavernous with voids up to 4cm wide and 0.5m deep.

The unit contains common *Globigerina* (of the *linaperta* group) and larger Foraminifera including *Nummulites fichteli*, *Lepidocyclina* (*Nepherolepidina*) and small benthonic Foraminifera. Burrows, oysters and colonial corals occur throughout.

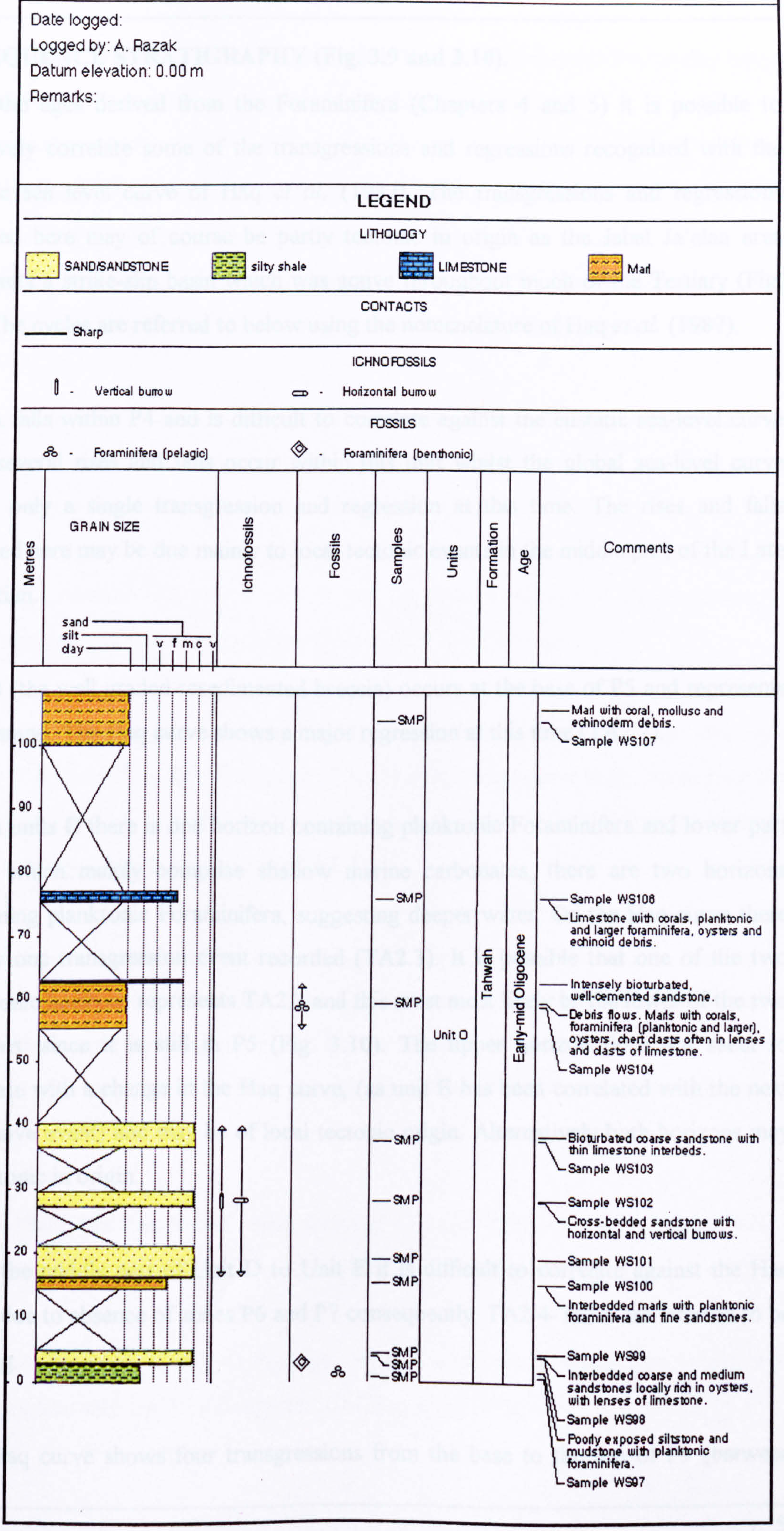
***Age***: Probably Lower Oligocene based on the cooccurrence of *Nummulites fichteli* and *Lepidocyclina* (*Nephrolepidina*) and the age of the underlying Unit N, although both taxa were also recorded from northern Oman by Racey (1995) from the mid-Oligocene.

***Thickness***: 114.5m.

***Environment***: Slope deposits based on the occurrence of planktonic Foraminifera such as *Globigerina linaperta* group, larger Foraminifera and corals in debris flows.

***Contact***: Disconformity at the base. Top contact not exposed.

Figure 3.8 **Lithostratigraphic Column of Unit O, Tahwah Formation Wadi Suq Section.**



## 3.4 SEQUENCE STRATIGRAPHY (Fig. 3.9 and 3.10).

From the ages derived from the Foraminifera (Chapters 4 and 5) it is possible to tentatively correlate some of the transgressions and regressions recognised with the eustatic sea level curve of Haq *et al.* (1987). The transgressions and regressions recorded here may of course be partly tectonic in origin as the Jabal Ja'alan area represents a strike-slip basin which was active throughout much of the Tertiary (Fig. 3.9). The cycles are referred to below using the nomenclature of Haq *et al.* (1987).

Unit A falls within P4 and is difficult to correlate against the eustatic sea-level curve since several rises and falls occur within this unit whilst the global sea-level curve shows only a single transgression and regression at this time. The rises and falls recorded here may be due mainly to local tectonic events in the middle part of the Late Thanetian.

Unit B (the well graded resedimented breccia) occurs at the base of P5 and represents a low stand. The Haq curve shows a major regression at this time (TA2.2).

Within units C there is one horizon containing planktonic Foraminifera and lower part of D, which mainly comprise shallow marine carbonates, there are two horizons containing planktonic Foraminifera, suggesting deeper water. On the Haq curve there is only one transgression event recorded (TA2.3). It is possible that one of the two planktonic horizons represents TA2.3 and this must most likely be the lower of the two horizons, since it is still in P5 (Fig. 3.10). The upper horizon does not seem to correlate with a change in the Haq curve, (as unit E has been correlated with the next regressive event) and may be of local tectonic origin. Alternatively both horizons may be tectonic in origin.

From the middle part of Unit D to Unit E it is difficult to correlate against the Haq curve due to absence of zones P6 and P7 consequently TA2.4-Ta2.6 are inferred to be missing.

The Haq curve shows four transgressions from the base to the top of P9 (between

TA2.7 and TA3.1), which occur within Unit F. It is possible that the four shaley layers with planktonic Foraminifera represent these transgressive events.

The two ankeritic horizons containing planktonic and larger Foraminifera noted within Unit G are very close together and represent flooding surfaces which may be equated with one of the four transgressions identified by Haq *et al.*, (1987). At present it is not possible to identify which of these transgressions these planktonic events represent.

Additional ankeritic horizons associated with oysters but lacking Foraminifera may represent more local flooding surfaces. Towards the middle of P10 the Haq curve shows a major regression. Perhaps the change from limestone to orange ankerite may reflect the onset of this event. The main indication of this regression may be the overlying sandstone (the lowest part of unit G), though the age of this sandstone is poorly defined and could be anywhere from top P9 to P12 in age.

There are several regressive events shown on the Haq curve throughout this time period (TA3.1 to 3.5). The first event (TA3.1) on the Haq curve is far larger than the others (TA3.2-TA3.5), and thus the sandstone at the base of Unit G is more likely to have been deposited then i.e. during TA3.1.

This sandstone is overlain by a dolomite then a palaeosol which is in turn overlain by another sandstone and palaeosol. The only age constraint comes from the dolomite (P12). These sediments represent two further regressions and are tentatively assigned to TA3.4 and early TA3.5 of Haq, though the age constraints on these are admittedly poor.

Unit H (marl) contains a deep water fauna of P12 age, implying a transgression which may represent the top of the TA3.5 cycle (Fig. 3.10) of Haq *et al.* (1987).

Unit I (carbonates), of P13 to P14 age, suggest a regression above Unit H and thus may correlate with the TA3.6 regression of Haq *et al.* (1987).

The ages of units J to N are mainly based on the larger Foraminifera and unkeeled planktonic Foraminifera. There are five cycles within these units. The basal cycle (P15) probably correlates with TA4.1 and the top cycle (P17) with TA4.3. The middle cycles suggest that sea level variation in this area was more complex than suggested by the Haq curve. Unit O represents P18 to P20, based on larger Foraminifera and is difficult to correlate against the global sea-level curve due to imprecise dating. The Haq curve does not show much variation over this time period so the changes seen in the section are probably due to local tectonically driven rises and falls in sea-level.

## 3.5 COMPARISON BETWEEN PREVIOUSLY PUBLISHED FAUNA AND THIS STUDY

Roger *et al.*, 1991 have identified (but not illustrated) a limited fauna from Oman comprising the planktonic Foraminifera: *Morozovella velascoensis, M. quetra, Acarinina mckanni, A. soldadoensis* and *Globigerina velascoensis* and the larger Foraminifera: *Alveolina pasticillata, Miscellanea miscella, Nummulites discorbinus, N.* aff. *gallensis, N.* cf. *lehneri, N. praediscorbinus, Sakesaria cotteri, Nummulites bullatus, N. fabianii, N. garnieri and Spiroclypeus margaritus* from this area compared to the forty one planktonic and twenty seven larger Foraminifera described and illustrated herein. In addition selected macrofossils have also been illustrated in this study (see Fig. 3.11, Fig. 3.12 and Fig. 3.13).

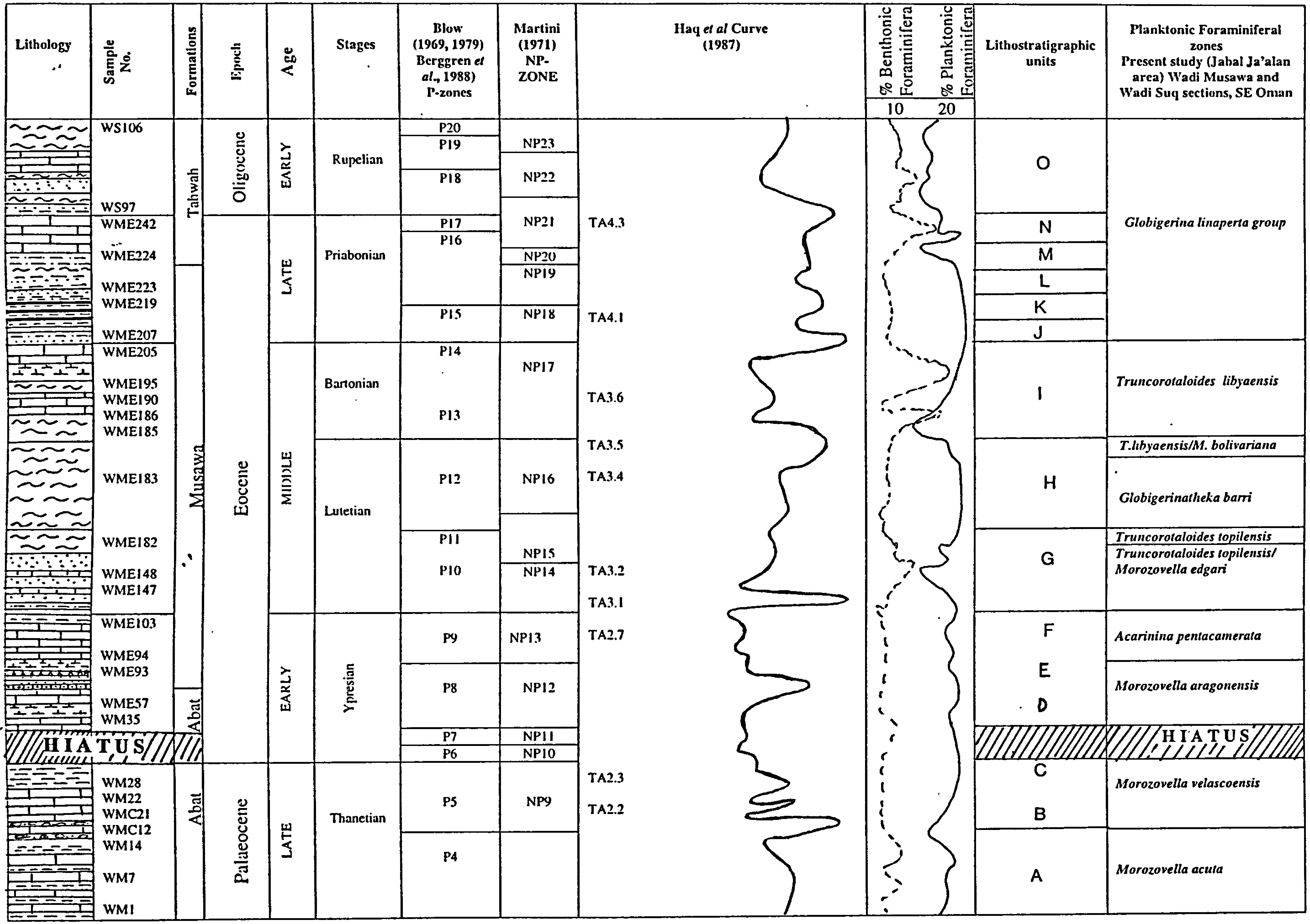



Fig. 3.9 Sequence stratigraphic framework. The calibration of local lithostratigraphic units against global bio- and sequence stratigraphic standards.

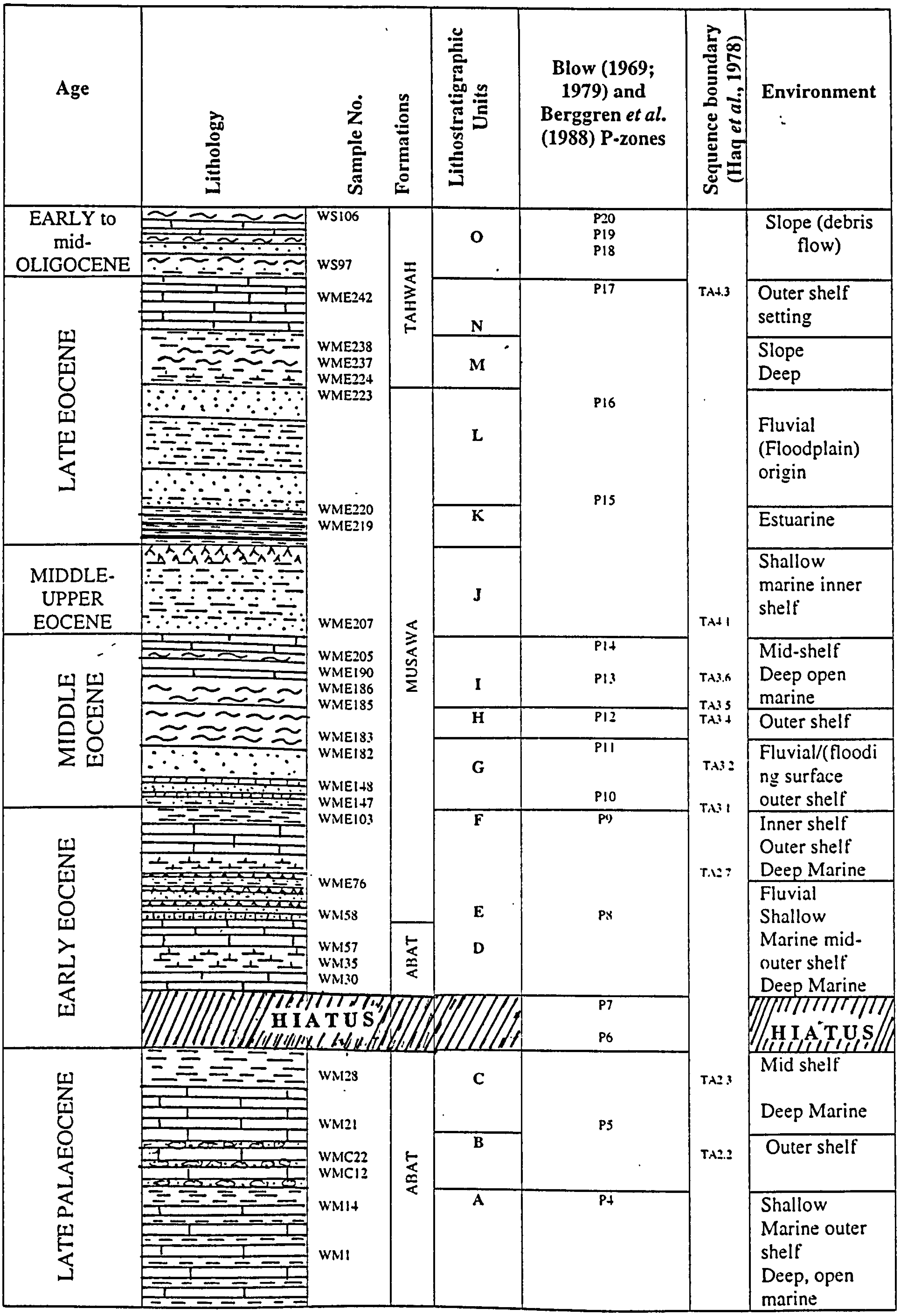



**Fig. 3.10 Stratigraphic column shows Lithostratigraphic units, biostratigraphic zones, and sequence boundary at the Wadi Musawa and Wadi Suq sections.**

| Formation | Fauna | Roger *et al.*, 1991 | This study |
|---|---|---|---|
| Abat Fm. | Planktonic Foraminifera | *Morozovella velascoensis*<br>*M. quetra*<br>*Acarinina soldadoensis*<br>*Acarinina mckannai*<br>*Globogerina velascoensis* | ***Morozovella acuta***<br>***M. angulata***<br>***M. velascoensis***<br>***Subottina triloculinoides***<br>***M. nicoli***<br>***M. pusilla mediterranica***<br>***M. occlusa***<br>***M.* sp. cf. *parva*** |
| | Larger Benthonic Foraminifera | *Miscellanea miscella*<br>*Nummulites praediscorbinus*<br>*N. aff. gallensis*<br>*N. cf. lehneri*<br>*N. discorbinus*<br>*Sakesaria cotteri*<br>*Alveolina pasticillata* | ***Daviesina iranica***<br>***D. shirazensis***<br>***Miscellanea primitiva***<br>***Operculina musawaensis nov.***<br>***Asterocyclina* sp. A** |
| | Macro | Gastropods | **Gastropods** |
| | Others | Corals, bryozoans and Echinoderms | **Echinoderms, Corals, bryozoans, Radiolaria and Ostracod species *Bairdia* sp.1, *Bairdia* sp.2, *Cytherella* sp.1, *Paracypris* cf. *sokotensis* R, *Phalcocythere* sp.1, *Bairdia* sp.3, *Bairdia* sp.4, *Xestoleberis* sp.1 and *Xestoleberis* sp.2** |

**Fig. 3.11 Comparison between previously published faunas mentioned (but not illustrated) by Roger *et al.*, (1991) for the Abat Formation with those recorded herein.**

| Formation | Fauna | Roger *et al.*, 1991 | This study |
|---|---|---|---|
| Musawa Fm. | Planktonic Foraminifera | Planktonic foraminifera not mentioned. | ***Acarinina pentacamerata A. soldadoensis, M. caucasica, M. crater, M. aragonensis, M. abundocamerata, M. bolivariana, M. aequa M. edgari, Globigerinatheka barri, G. curryi, G. euganea, G. subconglobata subconglobata, M. formosa formosa, M. gracilis, M. marginodentata, M. subbotinae, Subbotina quadrata, Truncorotaloides topilensis, T. libyaensis, Turborotalia blowcentralis nov. nov.*** |
| | Larger Benthonic Foraminifera | *Nummulites bullatus, N. discorbinus, N. fabianii, N. garnieri, Calcarina longispina Fabiania cassis and Heterostegina saipanensis* | ***Nummulites cf. atacicus, Nummulites fossulata, Nummulites discorbinus, N. maculatus, N. schaubi, Dictyoconus egyptiensis, Gypsina globulus, Coskinolina balsillei, Discocyclina dipansa, Linderina sp., Neorotalia omanensis nov.*** |
| | Macrofossils | *Bicorbula, Natica and Turritella* | ***Bicorbula, Natica and Turritella*** |
| | Others | Bryozoan and Echinoderms | **Ostracods, reworked Cretaceous radiolaria (*Mirifusus, Mita, Sethocapsa, Dictyomitra, Podobursa, Protunuma, Pseudodictyomitra, Triactoma, Ristola, Podobursa, Patellula, Holocryptocanium, and Conocaryomma*) Charophytes, Bryozoan and Insertae sedis** |

**Fig. 3.12 Comparison between previously published faunas mentioned (but not illustrated) by Roger *et al.*, (1991) for the Musawa Formation with those recorded herein.**

| Formation | Fauna | Roger *et al.*, 1991 | This study |
|---|---|---|---|
| Tahwah Fm. | Planktonic Foraminifera | *Globigerina* and *Globorotalia* | ***Globigerina linaperta*** **group** |
| | Larger Benthonic Foraminifera | *Nummulites fabianii*, *Nummulites garnieri* and *Spiroclypeus margaritatus* | ***Discocyclina javana*, *Nummulites Striatus*, *N. fichteli* *Lepidocyclina* (*Nephrolepidina*) sp. and *L.* (*Eulepidina*) sp.** |
| | Macrofossils | *Cardium*, *Nucula*, *Cerithium*, and Corals, | **Gastropods, Molluscs, and Corals** |
| | Others | Echinoderm and Bryozoan | **Ostracods and Echinoderms** |

**Fig. 3.13 Comparison between previously published faunas mentioned (but not illustrated) by Roger *et al.*, (1991) for the Tahwah Formation with those described and illustrated herein.**

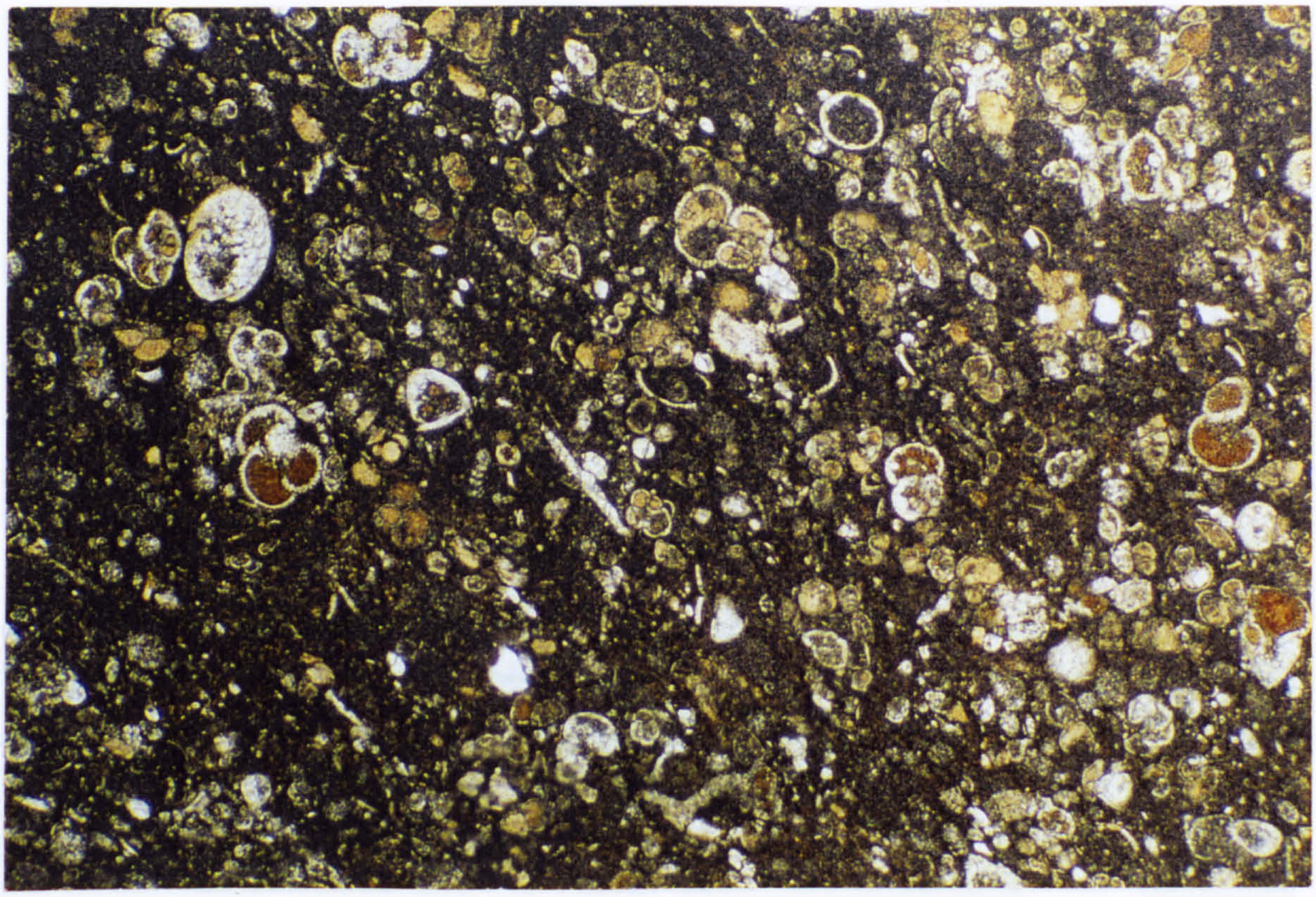


Plate 3.2.1.1a. Abat Formation. Unit A, sample WM5. Deep marine planktonic foraminiferal packstone. Late Palaeocene.

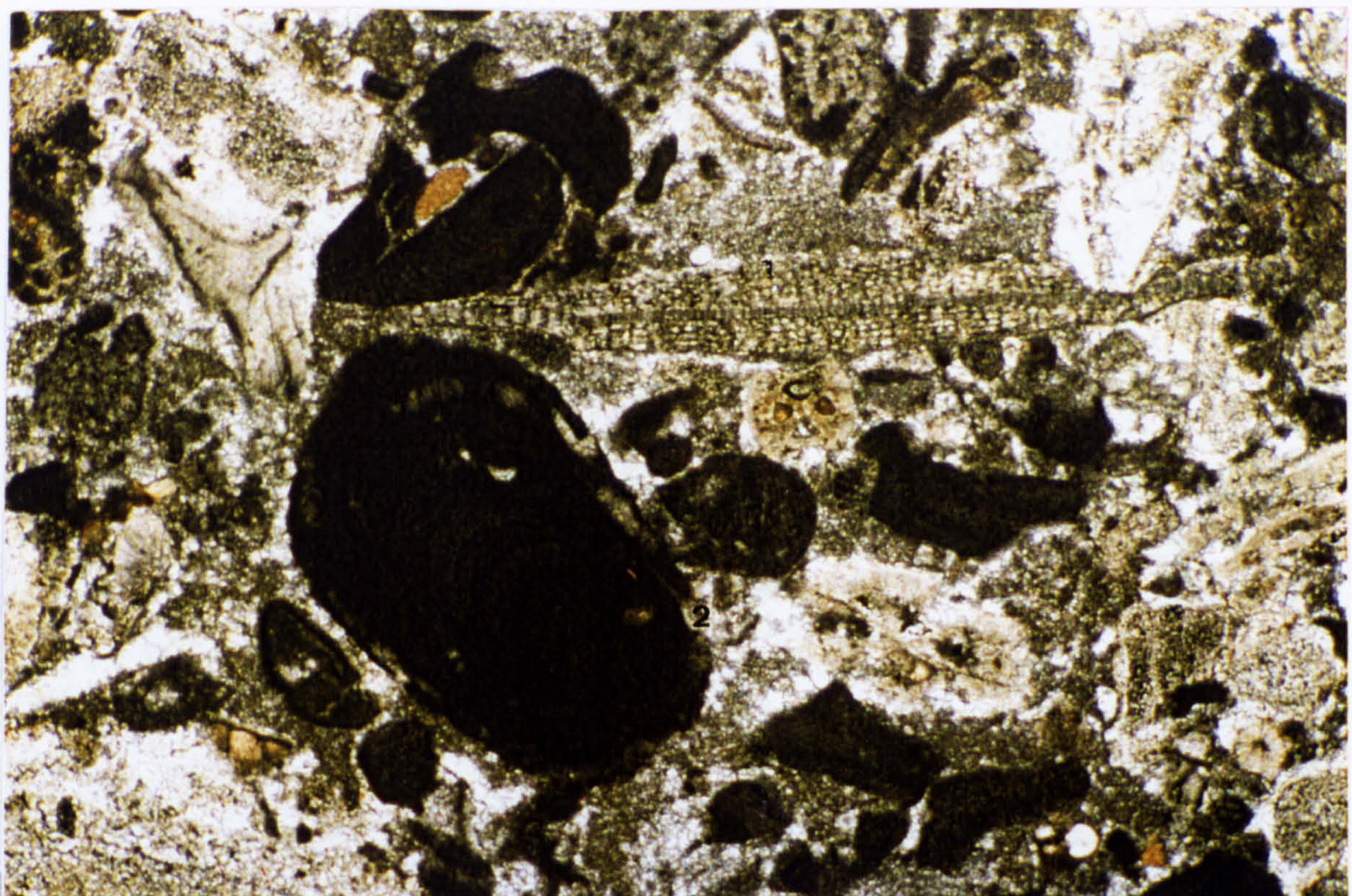



Plate 3.2.1.1b. Abat Formation. Unit A, sample WM14. Wackestone with *Discocyclina* (1) and red algae (2). Late Palaeocene.


Plate 3.2.1.1c. Abat Formation. Unit A, sample WM13Wackestone with *Assilina* (1), miliolids (2) and red algae (3). Late Palaeocene.

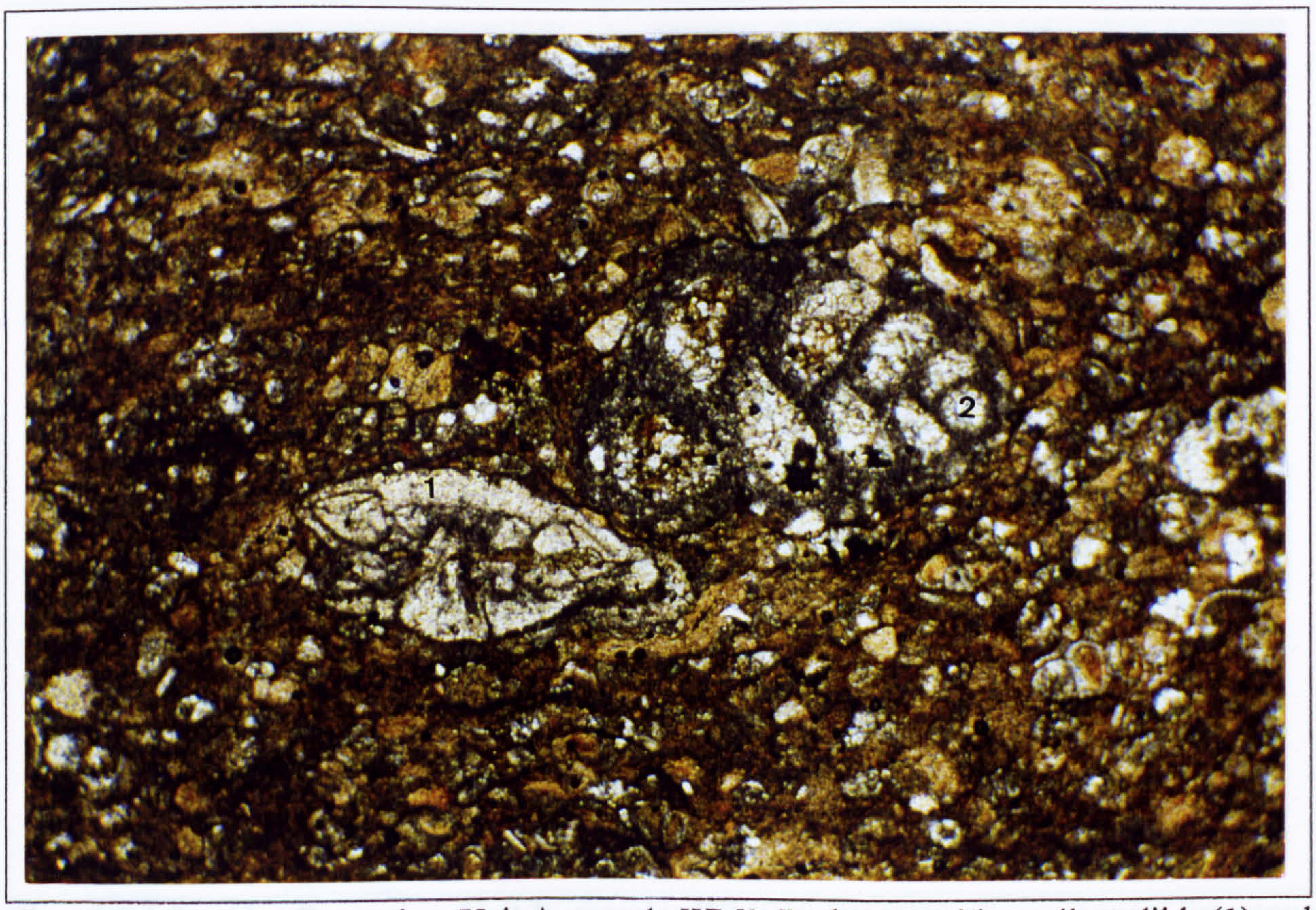



Plate 3.2.1.1d. Abat Formation. Unit A, sample WM2. Packstone with small rotaliids (1) and textulariids (2). Late Palaeocene.

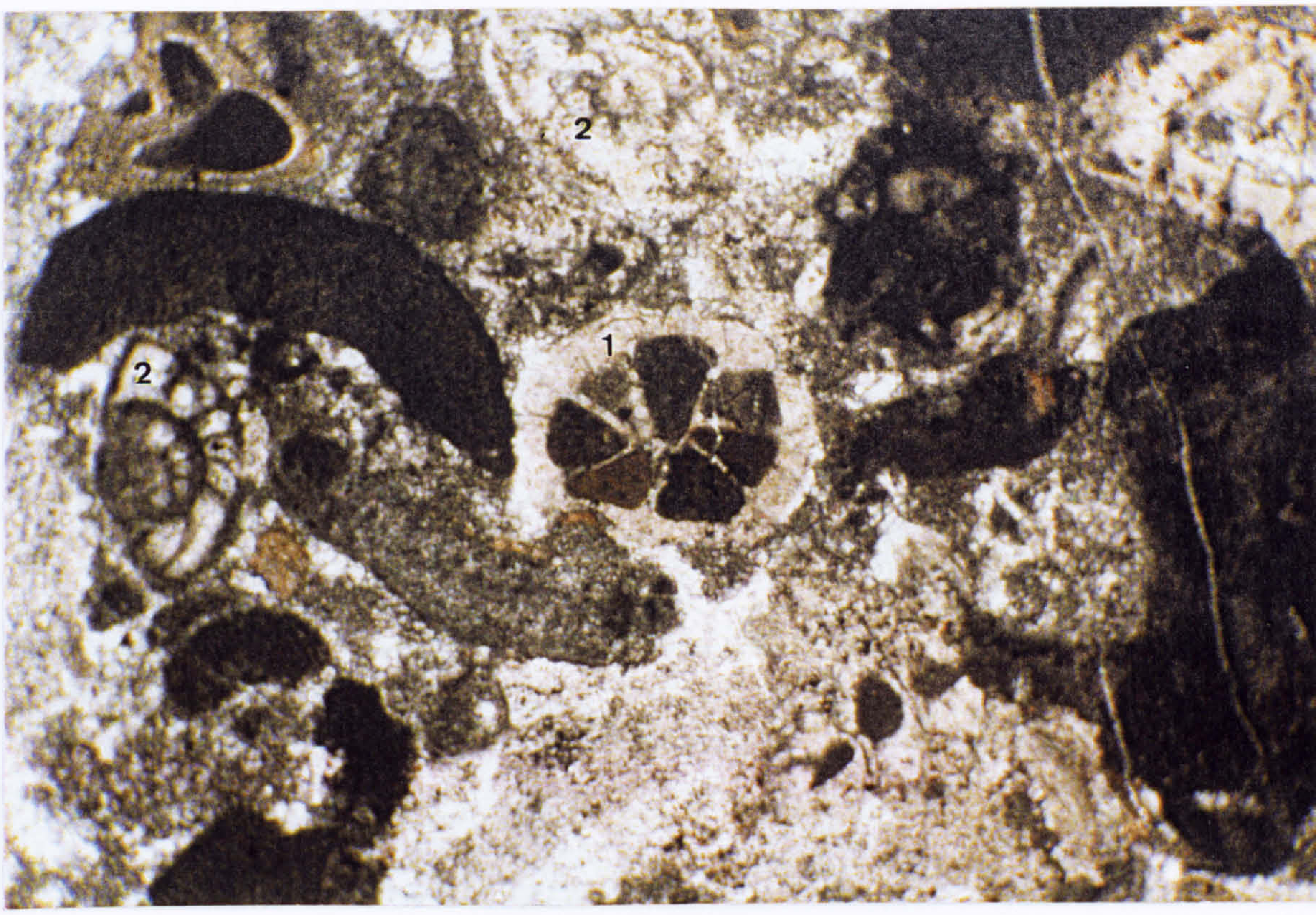



Plate 3.2.1.1e. Abat Formation. Unit A, sample WM14. Packstone with coral (1) and smaller rotaliids (2). Late Palaeocene.


Plate 3.2.1.2a. Abat Formation. Unit B, samples WMC12-WMC20. Six prominent limestone cycles, 1-6, respectively. Late Palaeocene.

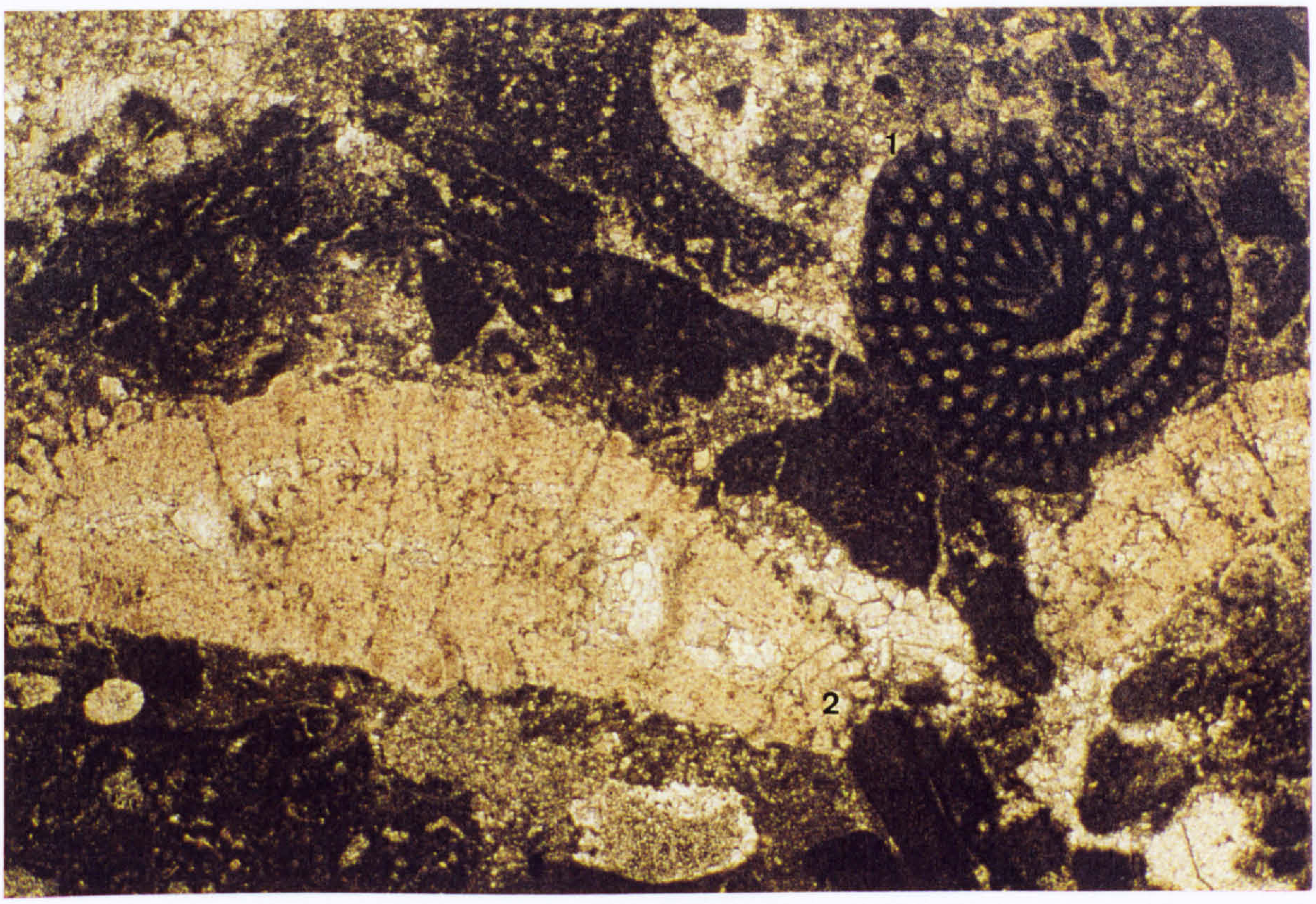


Plate 3.2.1.2b. Abat Formation. Unit B, sample WMC15. Packstone/wackestone with *Lacazinalla* (1) and rotaliid foraminifera (2). Late Palaeocene.

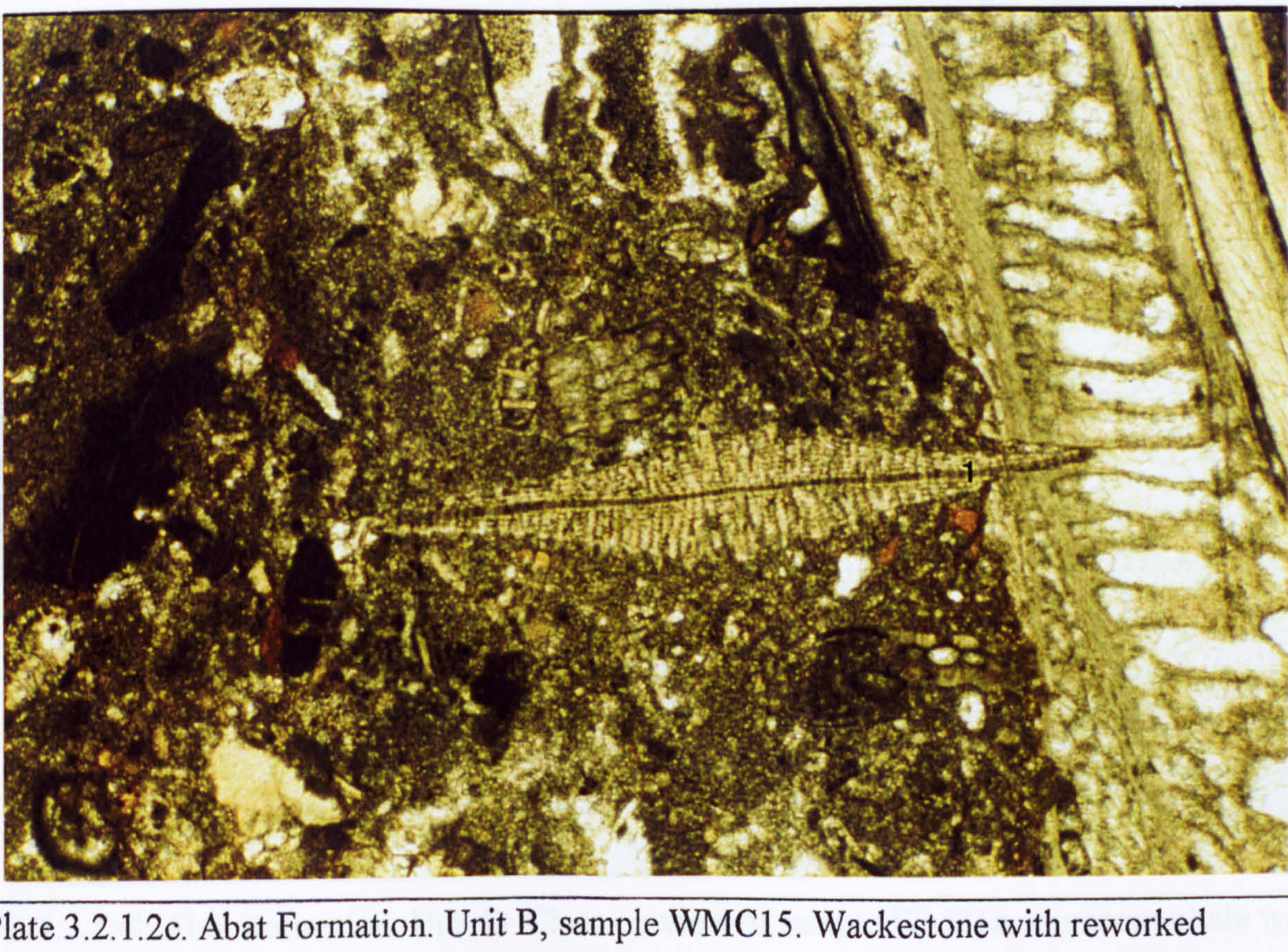


Plate 3.2.1.2c. Abat Formation. Unit B, sample WMC15. Wackestone with reworked *Discocyclina* (1). Late Palaeocene.


Pl. 3.2.1.4a Abat Formation. Unit D, samples WM30 and WM31a. Wackestone (1) and Mudstone/shale (2) respectively. Early Eocene.


Pl. 3.2.1.4b Abat Formation. Unit D. Close up view of sample WM31a, mudstone/shale with larger foraminifera *Nummulites* (1) and *Assilina* (2). Early Eocene.

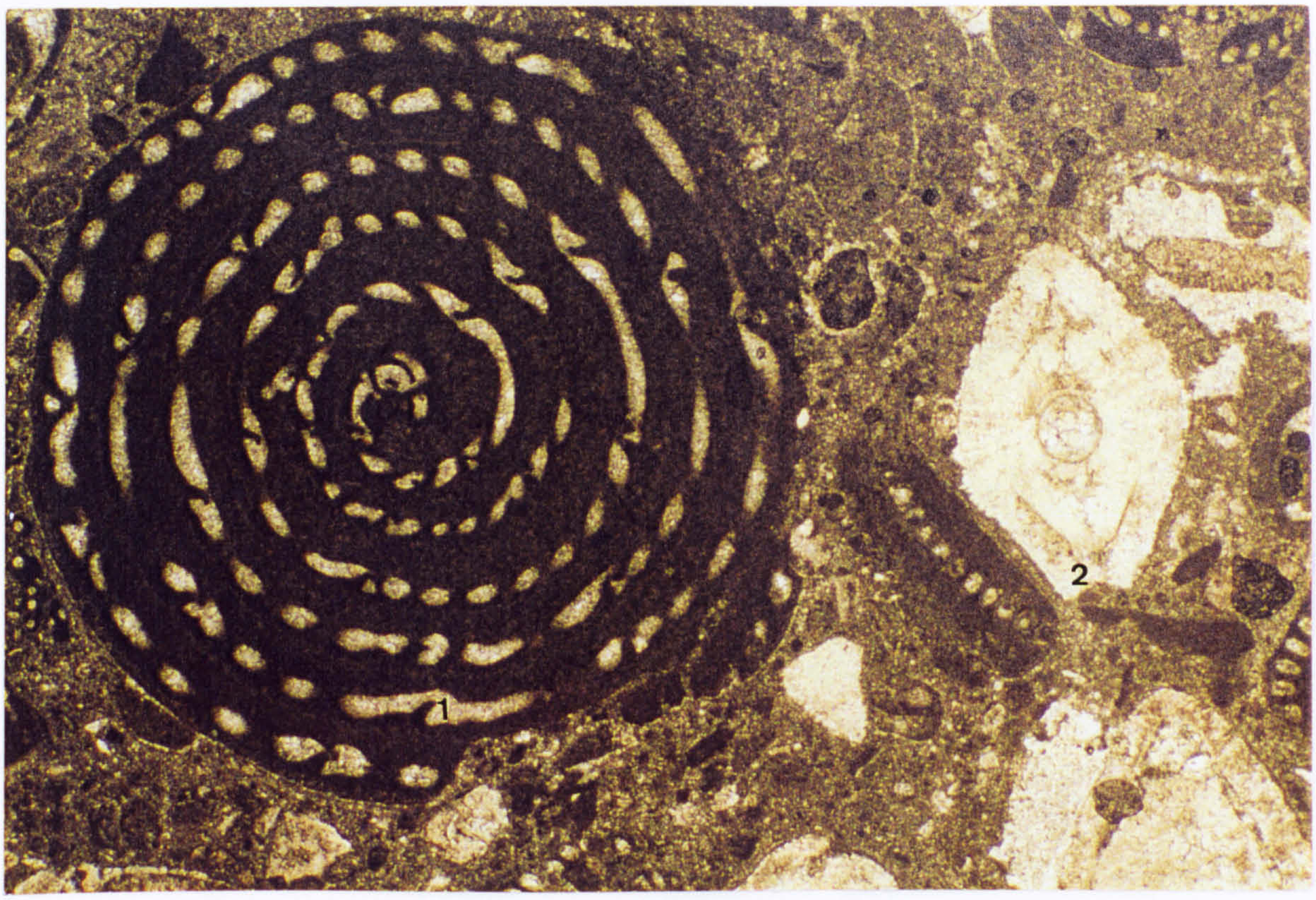



Plate 3.2.1.4c. Abat Formation. Unit D, sample WM29. Wackestone with *Alveolina* (1) and *Nummulites* (2). Early Eocene.

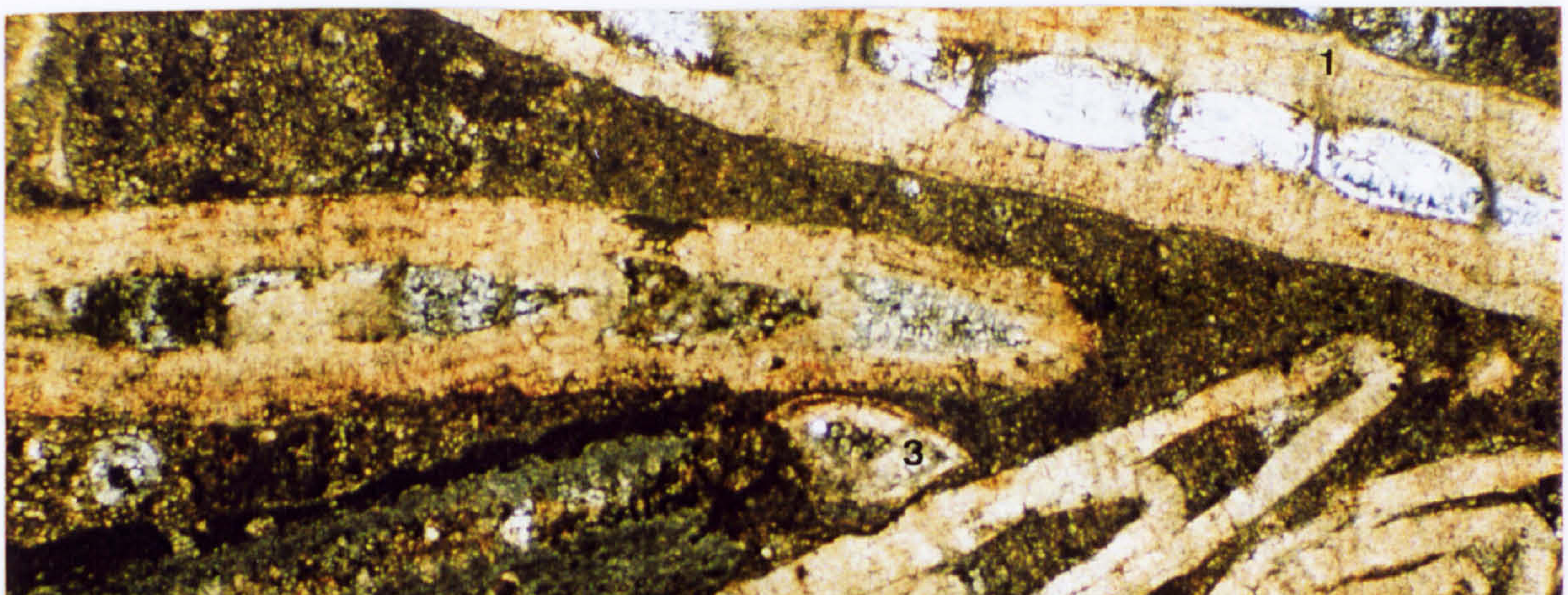



Plate 3.2.1.4d. Abat Formation. Unit D, sample WM48. Packstone with *Assilina* (1), *Nummulites* (2), and *Somalina* (3). Early Eocene.

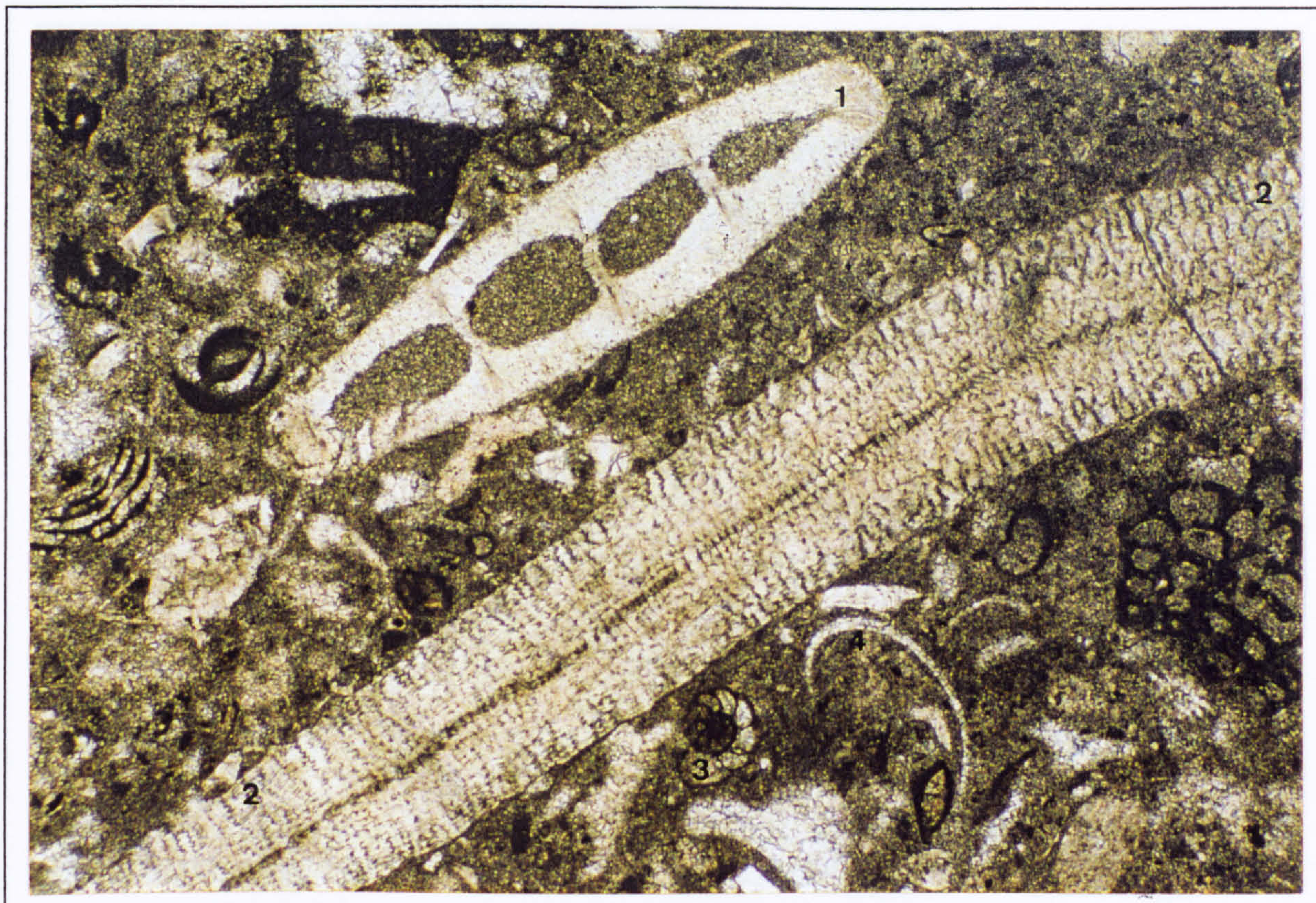



Plate 3.2.1.4e. Abat Formation. Unit D, sample WM41. Packstone with *Assilina* (1), *Discocyclina* (2), small rotaliids (3) and ostracoda (4). Early Eocene.

Plate 3.2.1.4f. Abat Formation. Unit D, sample WM56. *Somalina* packstone. Early Eocene.


Plate 3.2.1.4g. Abat Formation. Unit D, sample WM34. Mudstone with *Actinocyclina* (1). Early Eocene.

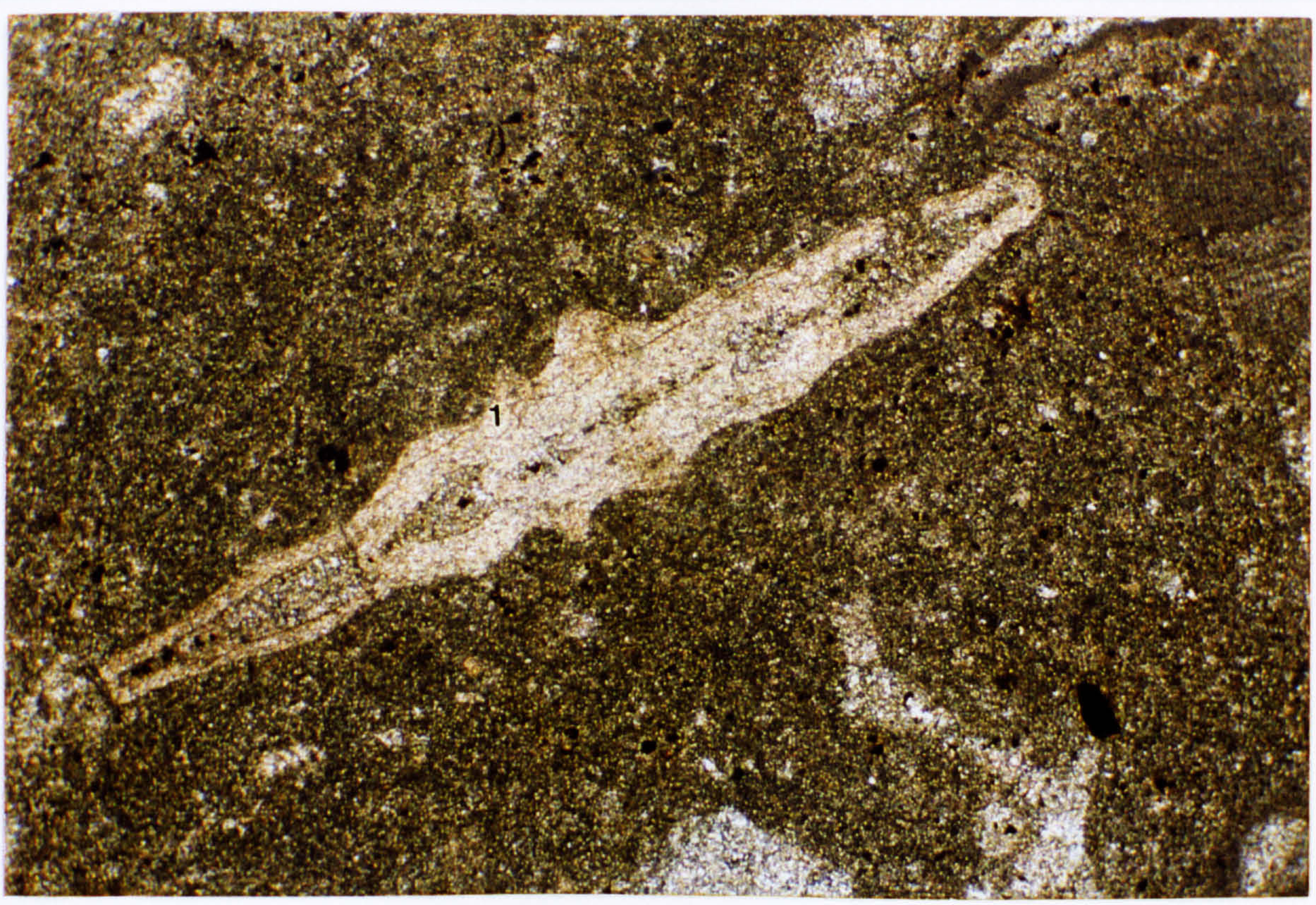



Plate 3.2.1.4h Abat Formation. Unit D, sample WM34. Mudstone with *Operculina* (1). Early Eocene.


Plate 3.2.1.4i. Abat Formation. Unit D, sample WM31b. Packstone with cf. *Ranikothalia* (1), *Textularia* (2) and Mollusc fragments. Early Eocene.

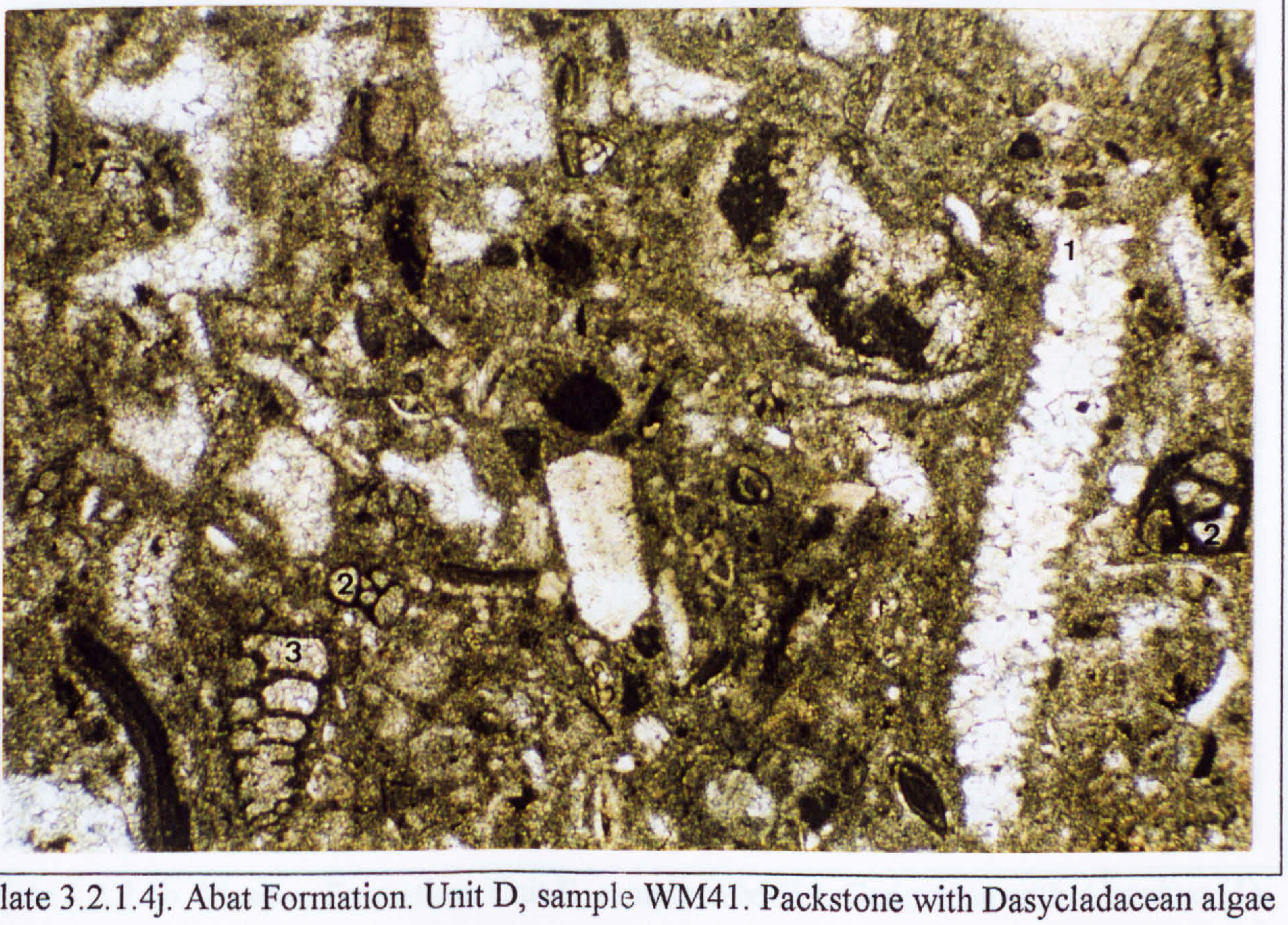



Plate 3.2.1.4j. Abat Formation. Unit D, sample WM41. Packstone with Dasycladacean algae (1), miliolids (2) and Textulariids (3). Early Eocene.

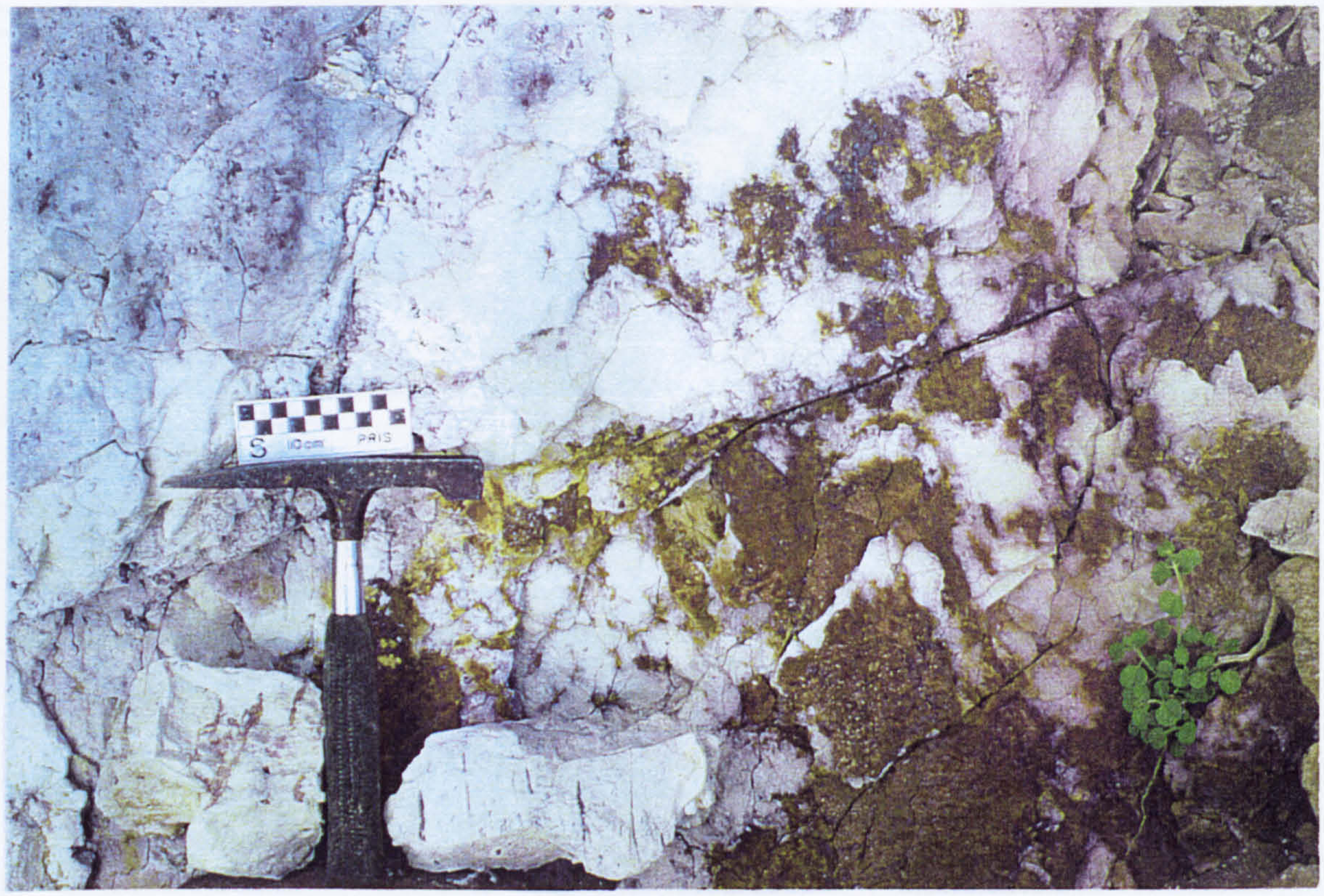


Plate 3.2.2.1a. Musawa Formation. Unit E, sample 30P1. A palaeosol with rootlets and very thin layers of fine grained sandstone. Early Eocene.

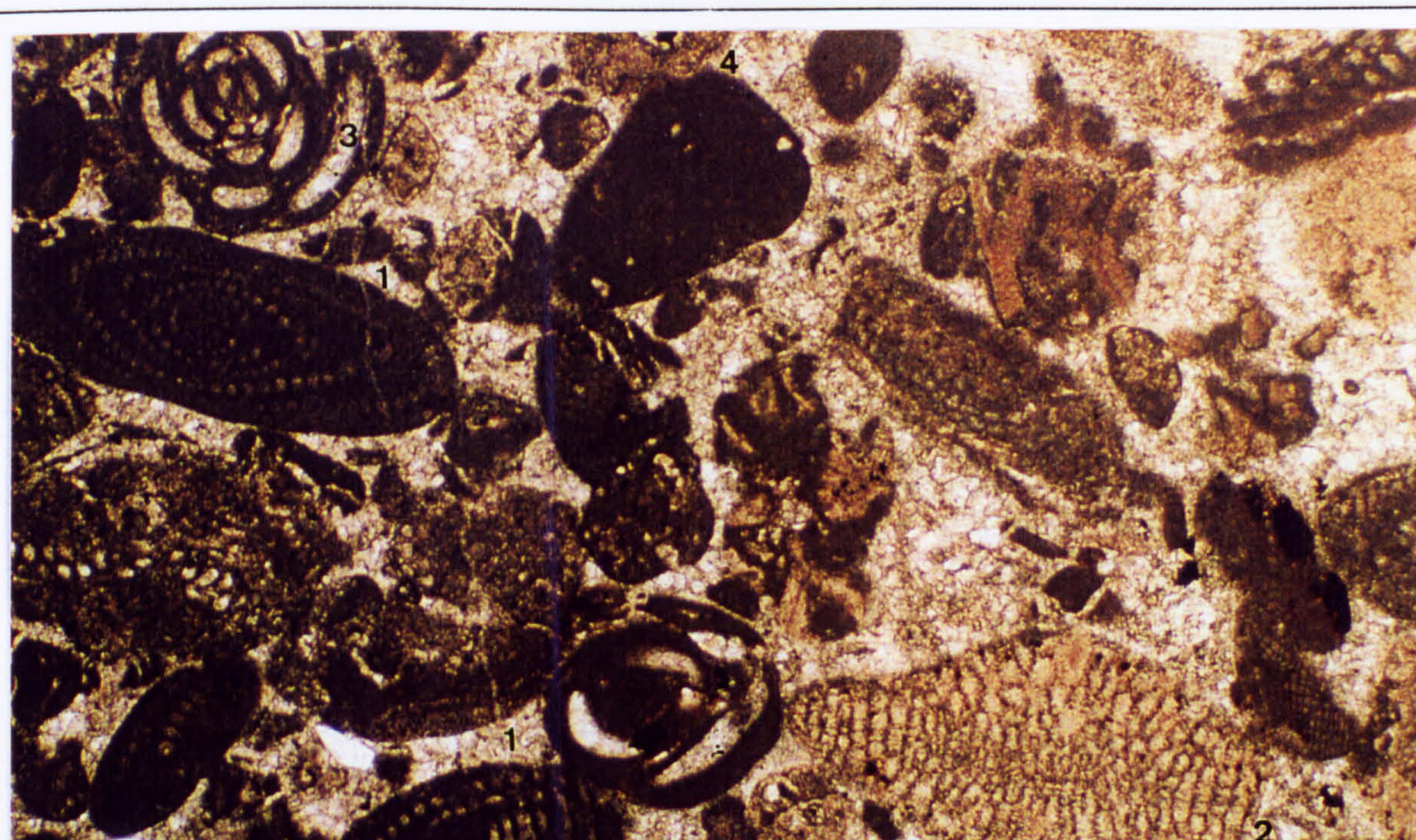



Plate 3.2.2.1b. Musawa Formation. Unit E, sample WME59. Grainstone with *Alveolina* (1), *Discocyclina* (2), miliolids (3) and red algae (4). Early Eocene.

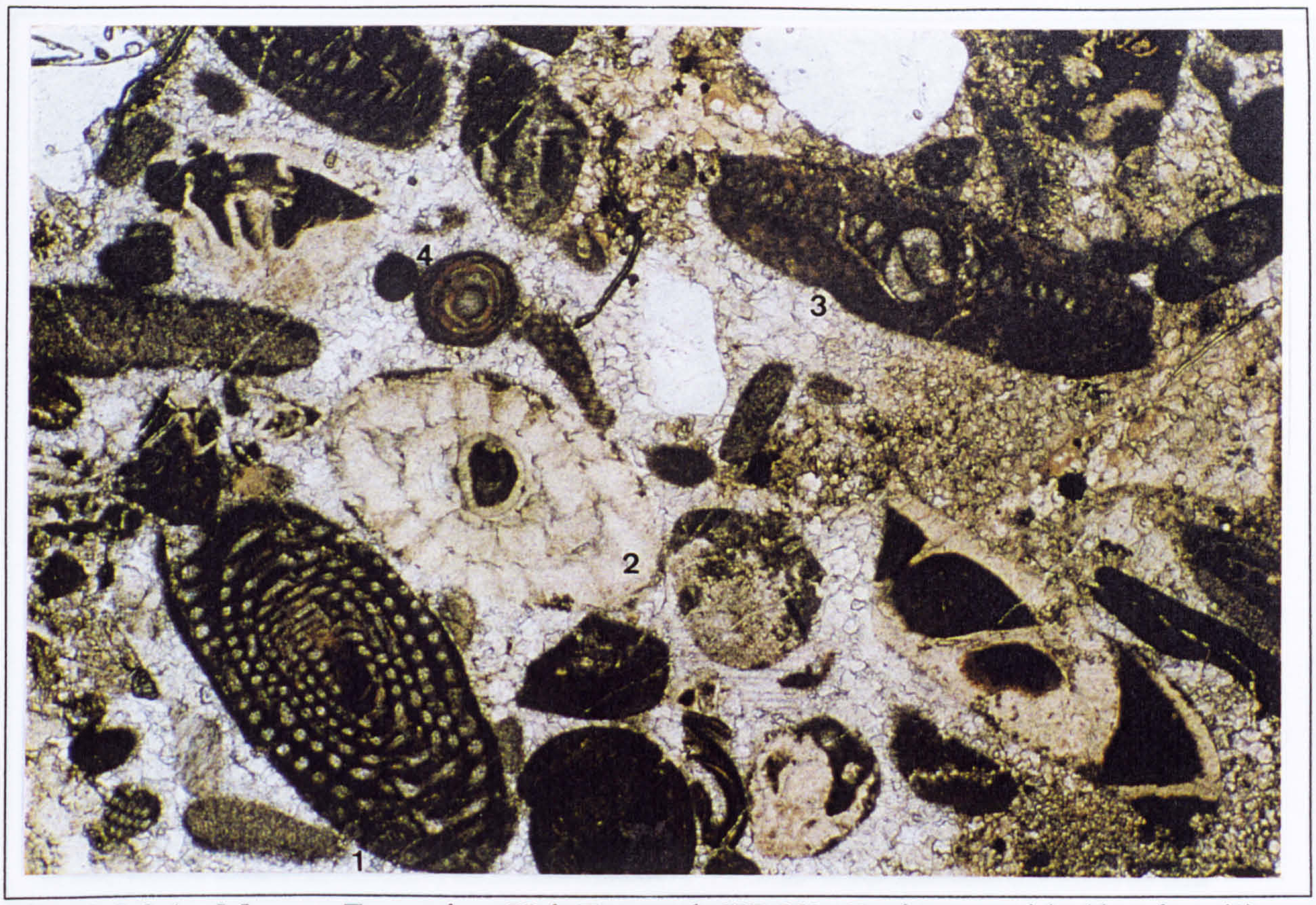



Plate 3.2.2.1c. Musawa Formation. Unit E, sample WM60. Packstone with *Alveolina* (1), *Nummulites* (2) *Somalina* (3) and miliolids (4). Early Eocene.


Plate 3.2.2.1d. Musawa Formation. Unit E, sample WM60. Packstone with *Assilina* (1), miliolids (2) and red algae (3). Early Eocene.


Plate 3.2.2.1e. Musawa Formation. Unit E, sample WM58. Packstone with *Alveolina* (1), miliolids (2) and smaller Rotaliids (3). Early Eocene.


Plate 3.2.2.2a. Musawa Formation. Unit F, sample WME85. Mudstone with Branching Bryozoans (1). Early Eocene.

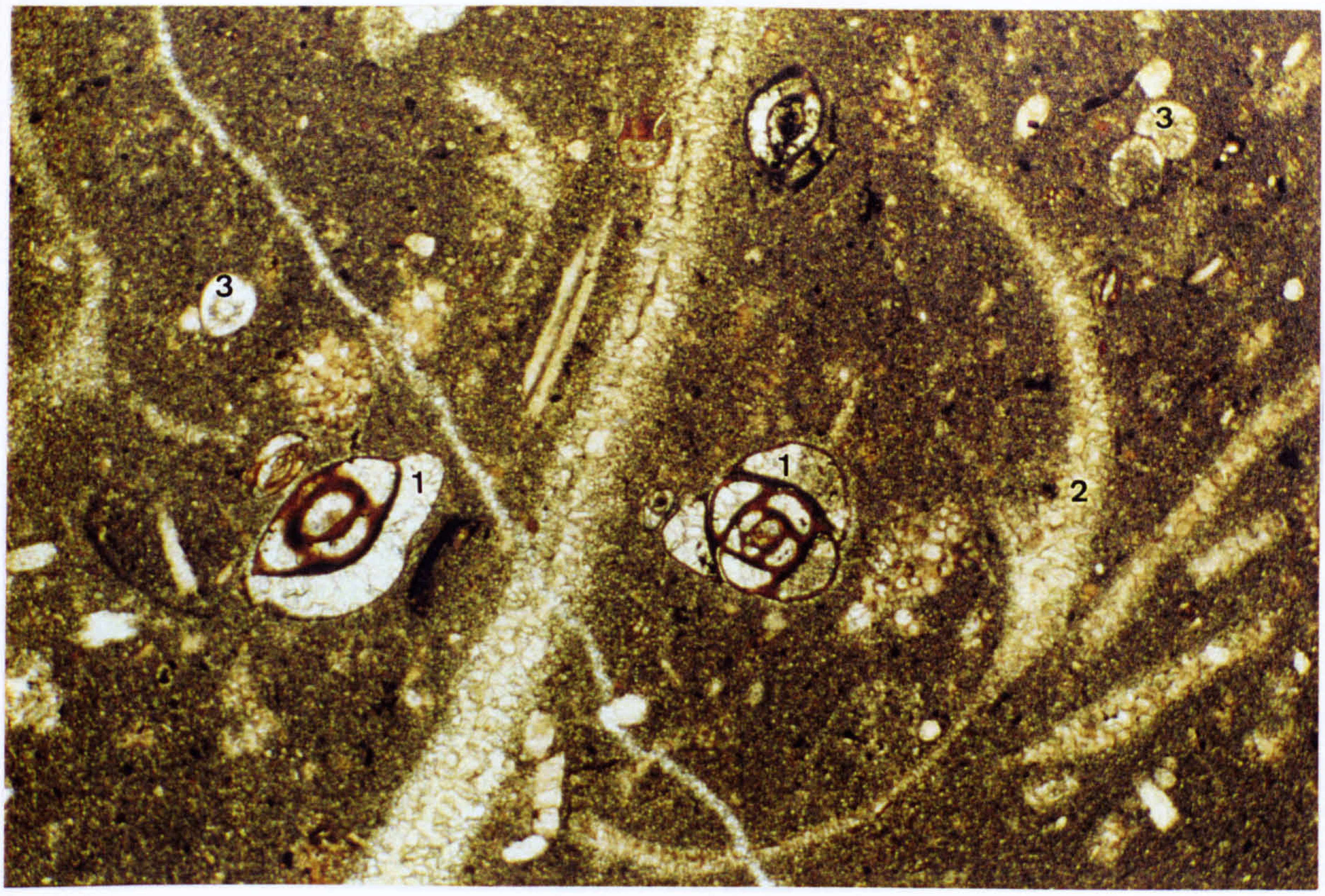



Plate 3.2.2.2b. Musawa Formation. Unit F, sample WME109. Mudstone/wackestone with miliolids (1), mollusc fragments (2) and reworked radiolaria (3). Early Eocene.

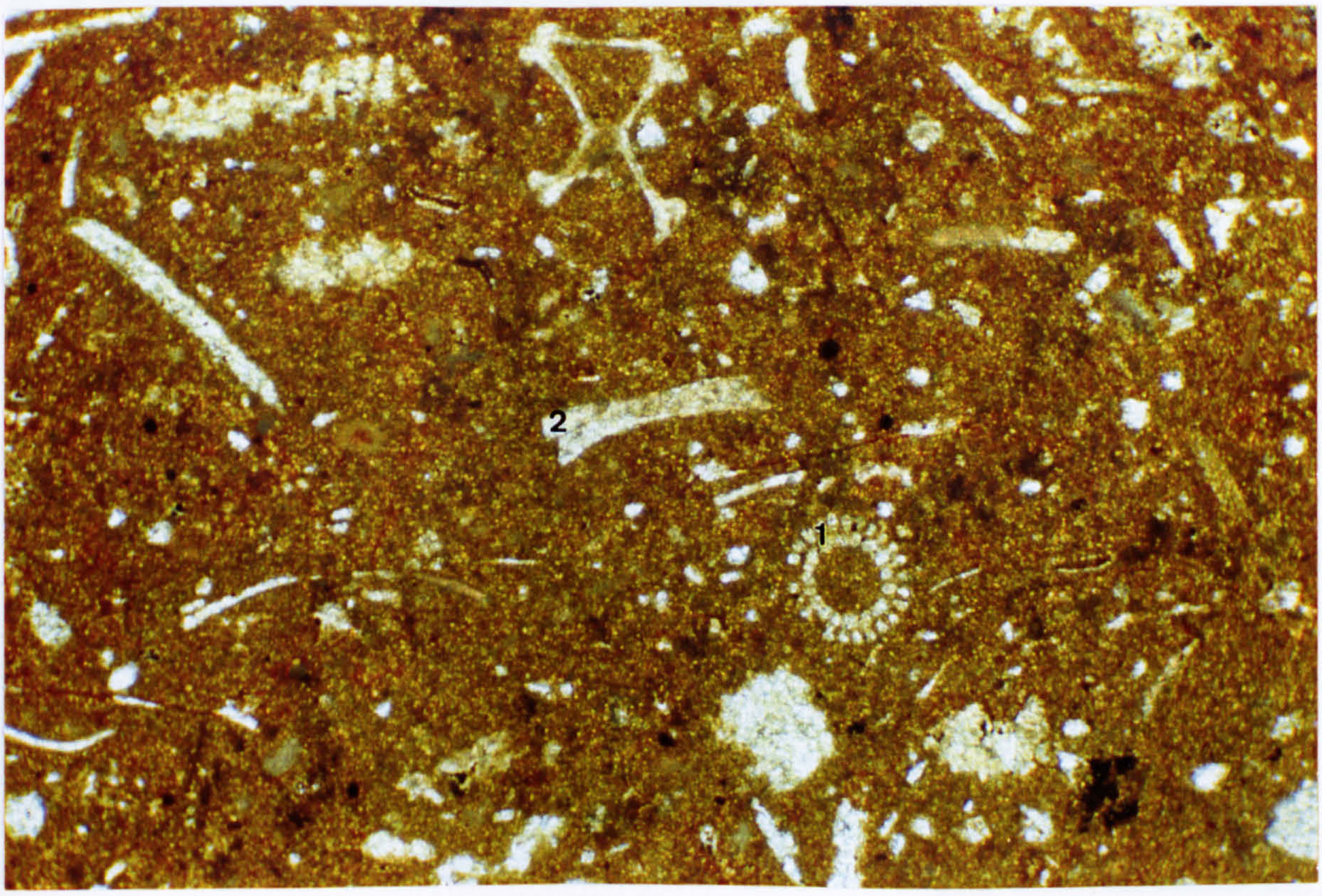



Plate 3.2.2.2c. Musawa Formation. Unit F, sample WME110. Wackestone with echinoids plates and spines (1) and mollusc fragments (2). Early Eocene.

Plate 3.2.2.3a. Musawa formation. Unit G. Second fluvial package which is mainly of medium grained sandstone. Middle Eocene.

Plate 3.2.2.3b. Musawa Formation. Unit G. Poorly developed palaeosols with very thin layers of gypsum. Middle Eocene.

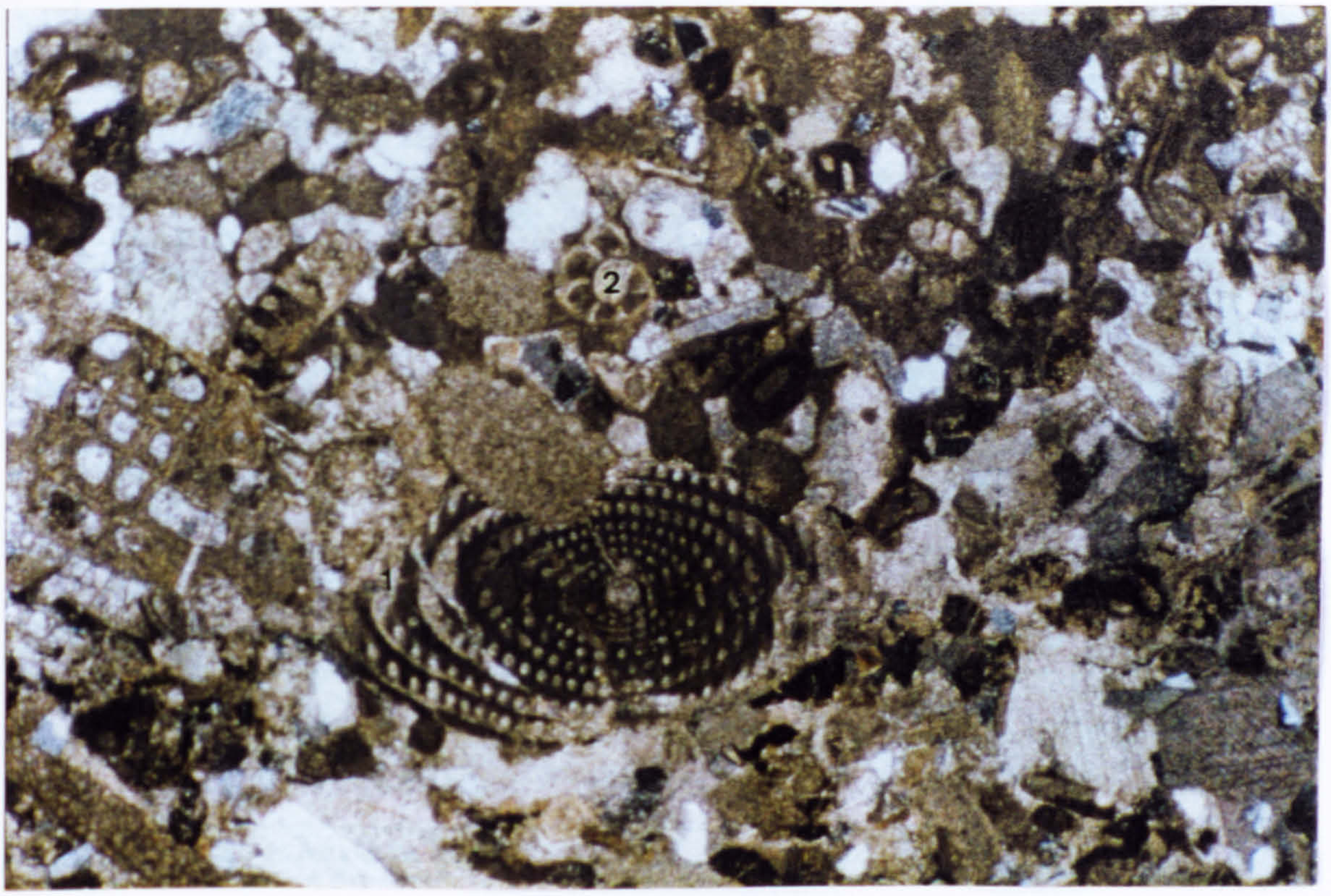



Plate 3.2.2.3c. Musawa formation. Unit G, sample WME114. Sandy limestone with reworked *Alveolina* (1) and small rotaliids (2). Early Eocene.

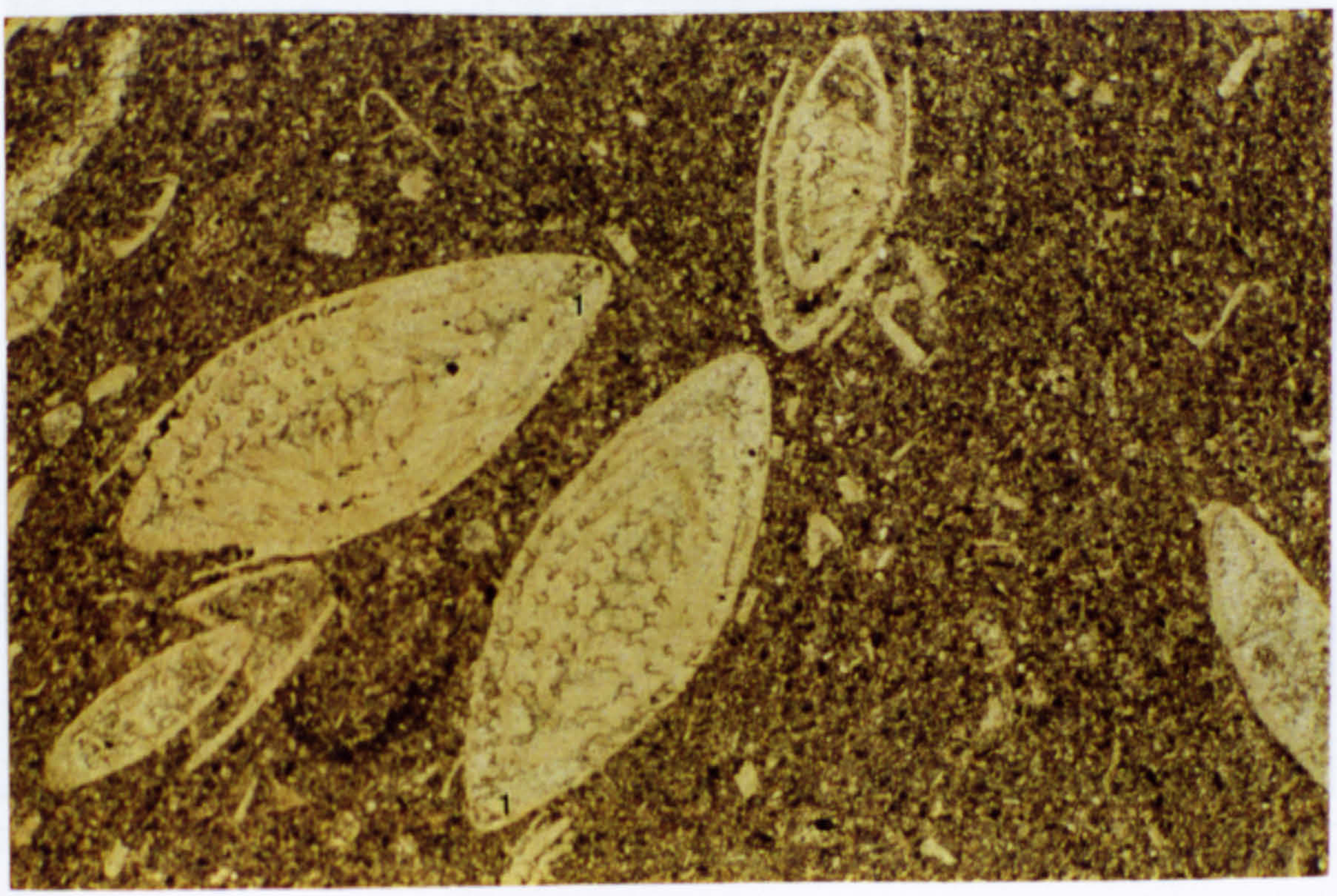



Plate 3.2.2.5a. Musawa Formation. Unit I, sample WME195. Wackestone with *Nummulites* (1). Middle Eocene.

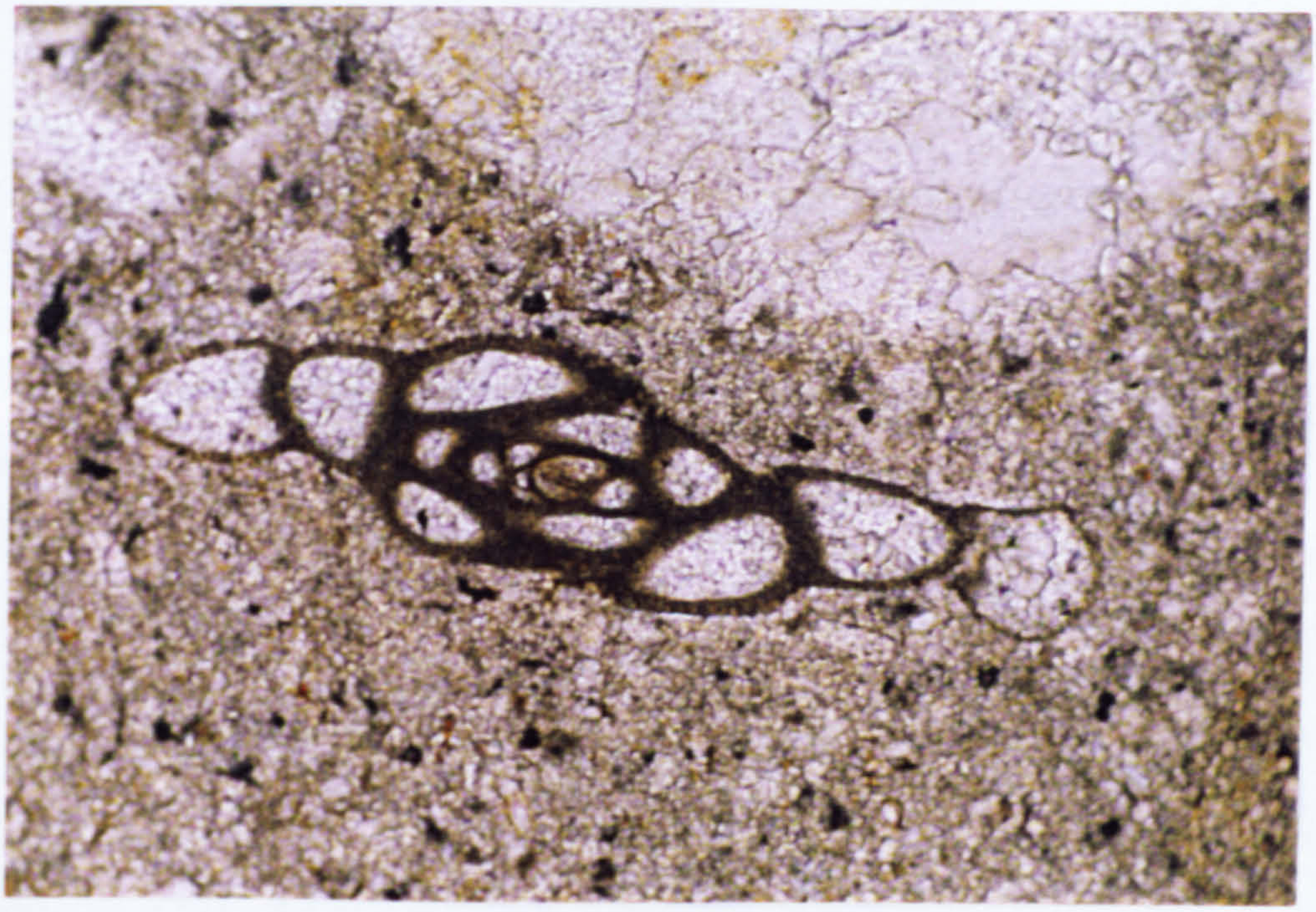


Plate 3.2.2.5b. Musawa Formation. Unit I, sample WME197. Mudstone with oblique section through miliolid. Middle Eocene.

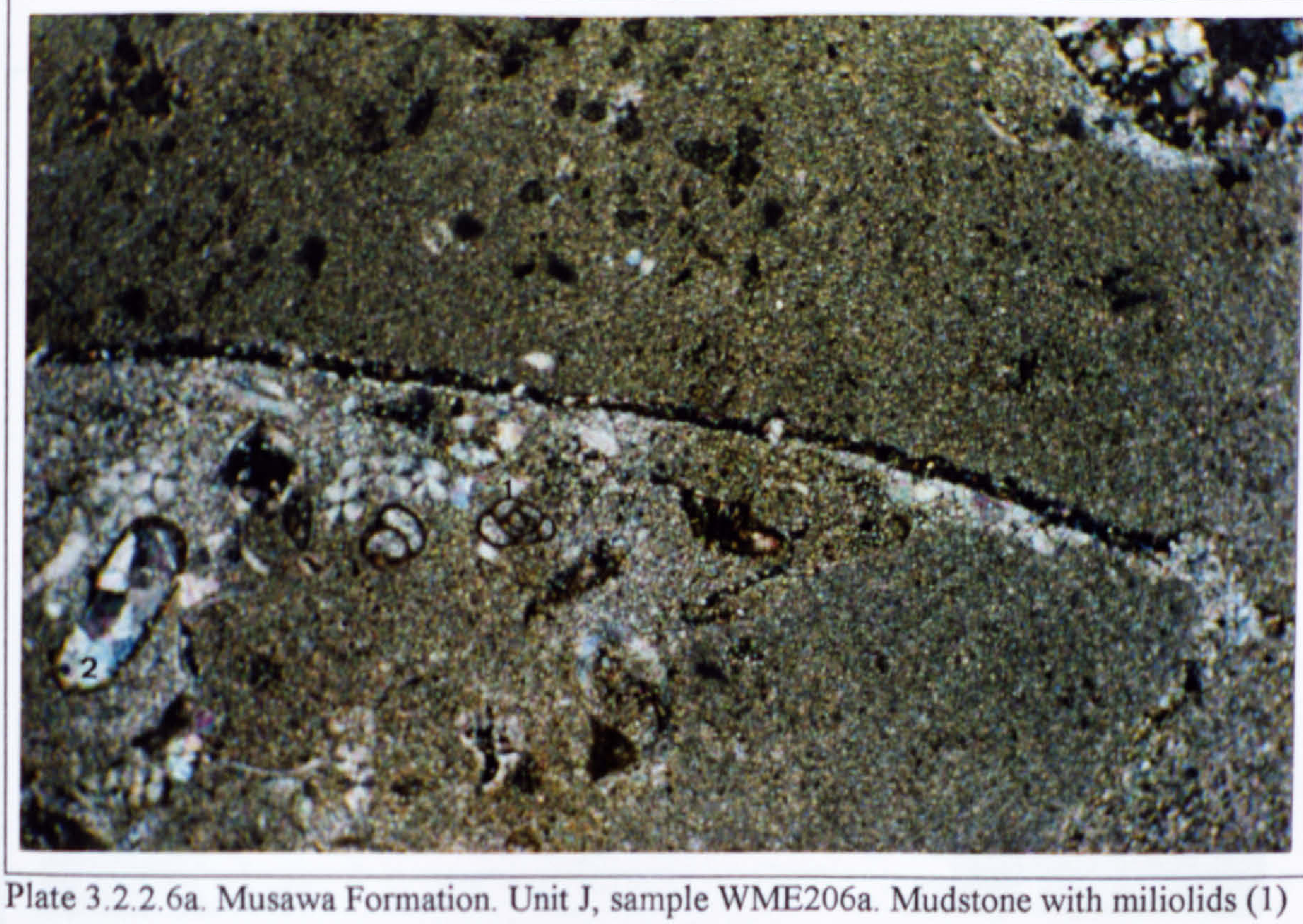
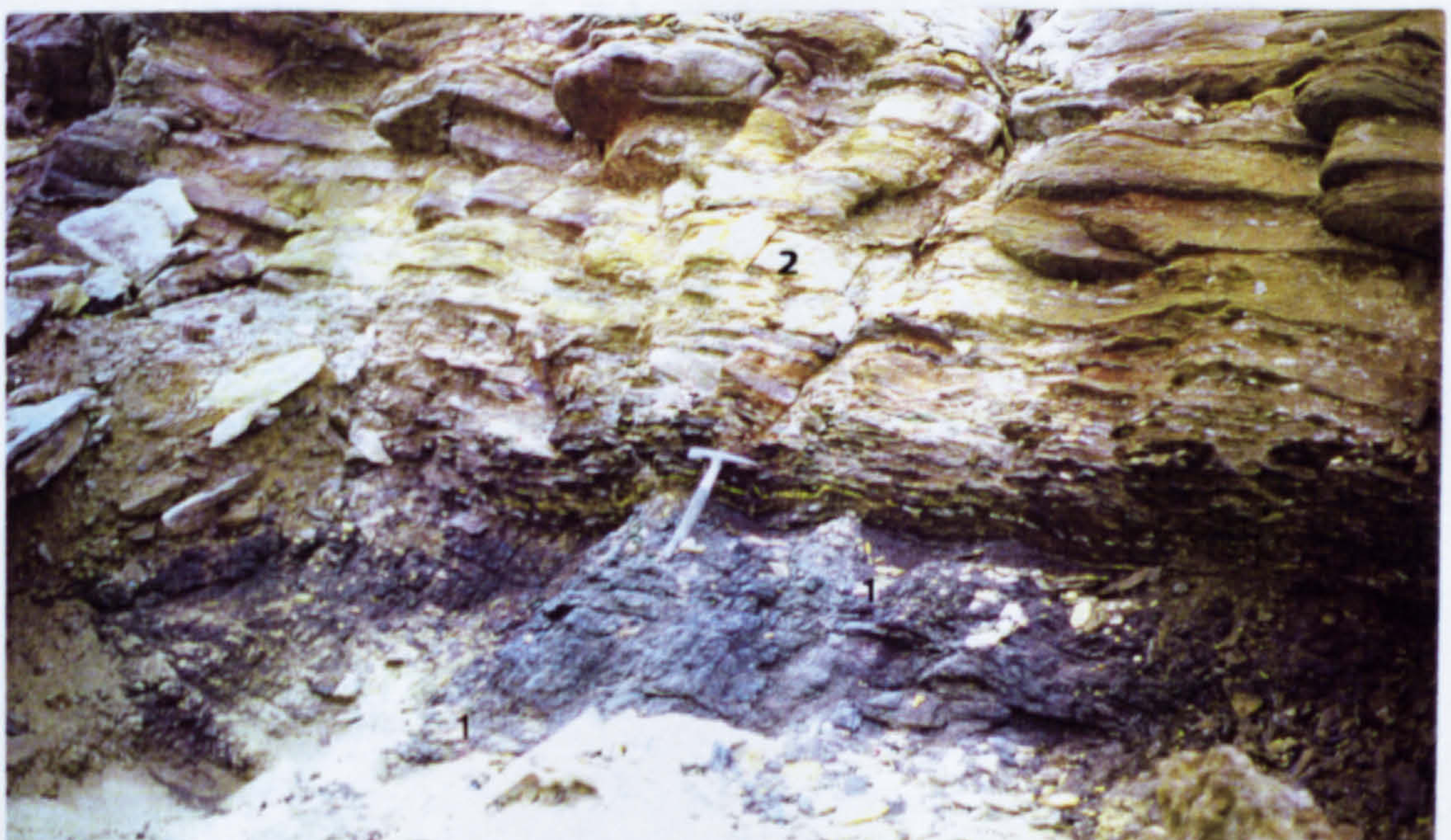
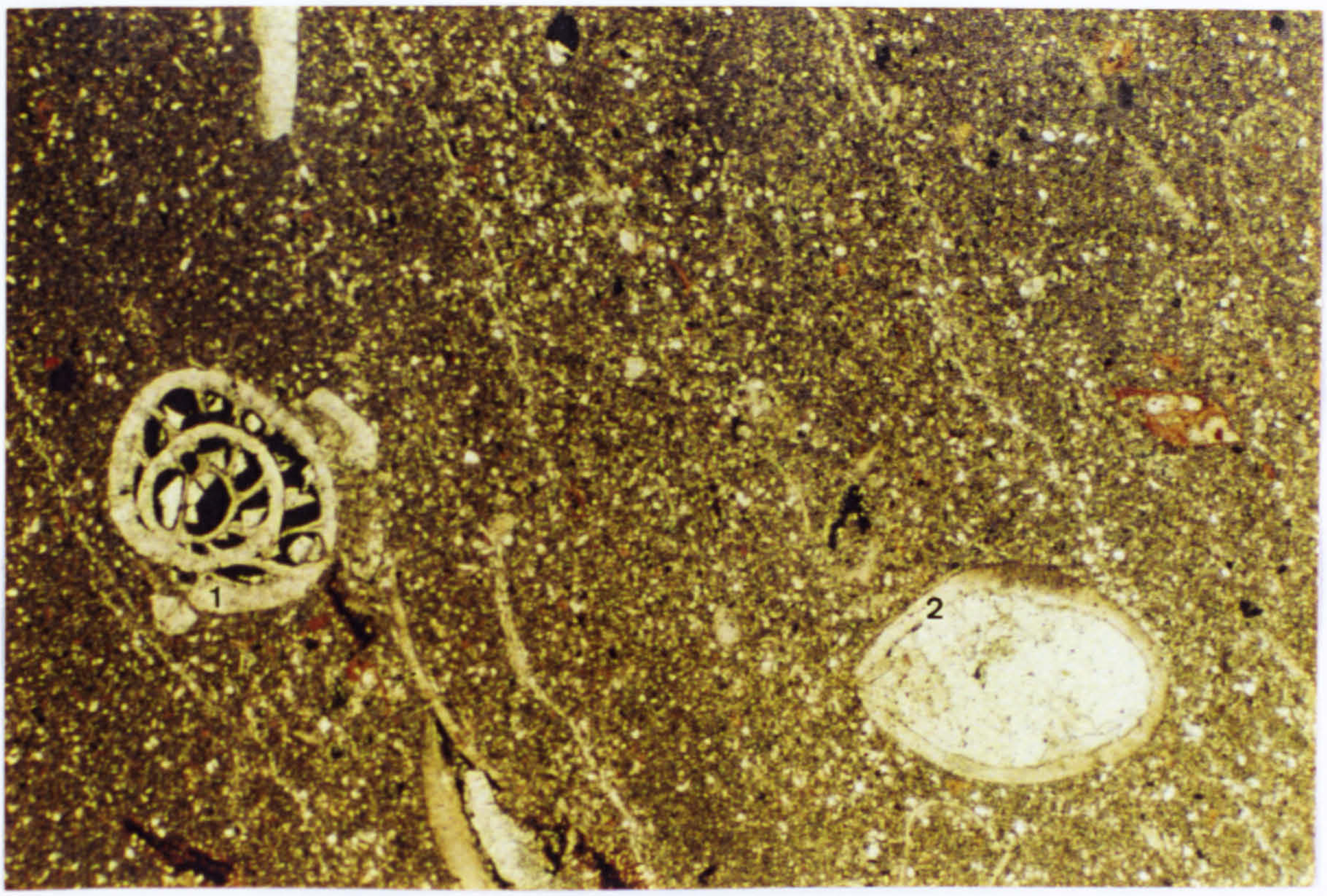



Plate 3.2.2.6a. Musawa Formation. Unit J, sample WME206a. Mudstone with miliolids (1) and ostracods (2). Middle Eocene.

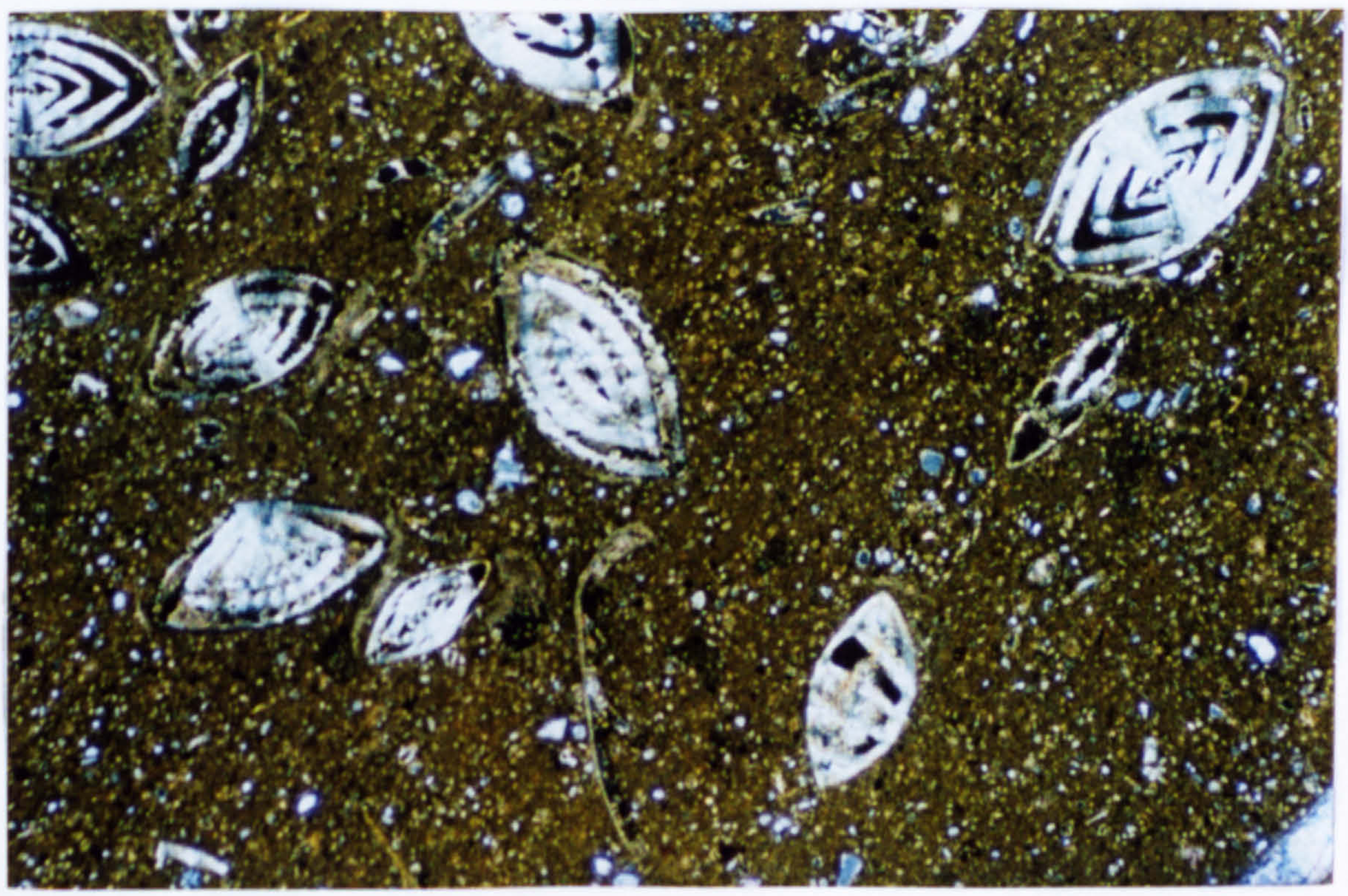
Pl. 3.2.2.6b Musawa Formation. Unit J. Fine-grained sandstone with cross-bedding. Middle to Late Eocene.




Pl. 3.2.2.7a Musawa Formation. Unit K, sample WME219N. A meter thick of coal seam (1) at the top of unit K, overlain by massive sandstone (2). Late Eocene.




Pl. 3.2.3.2a Tahwah Formation. Unit M, sample WME226. Mudstone/shale with *Nummulites* (1) and ostracod (2). Late Eocene



Pl. 3.2.3.2b Tahwah Formation. Unit M, sample WME234. Wackestone with small *Nummulites*. Late Eocene.

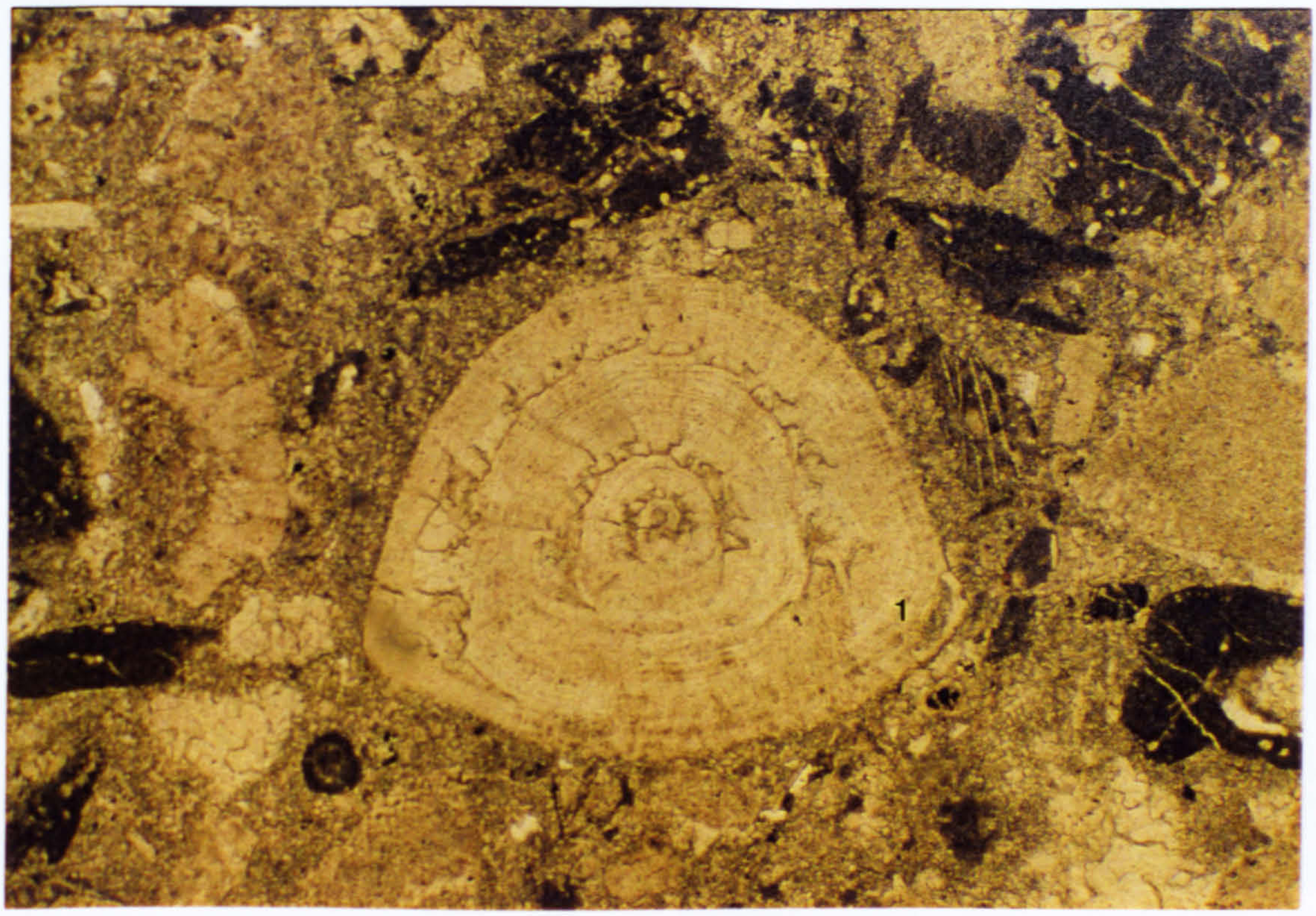
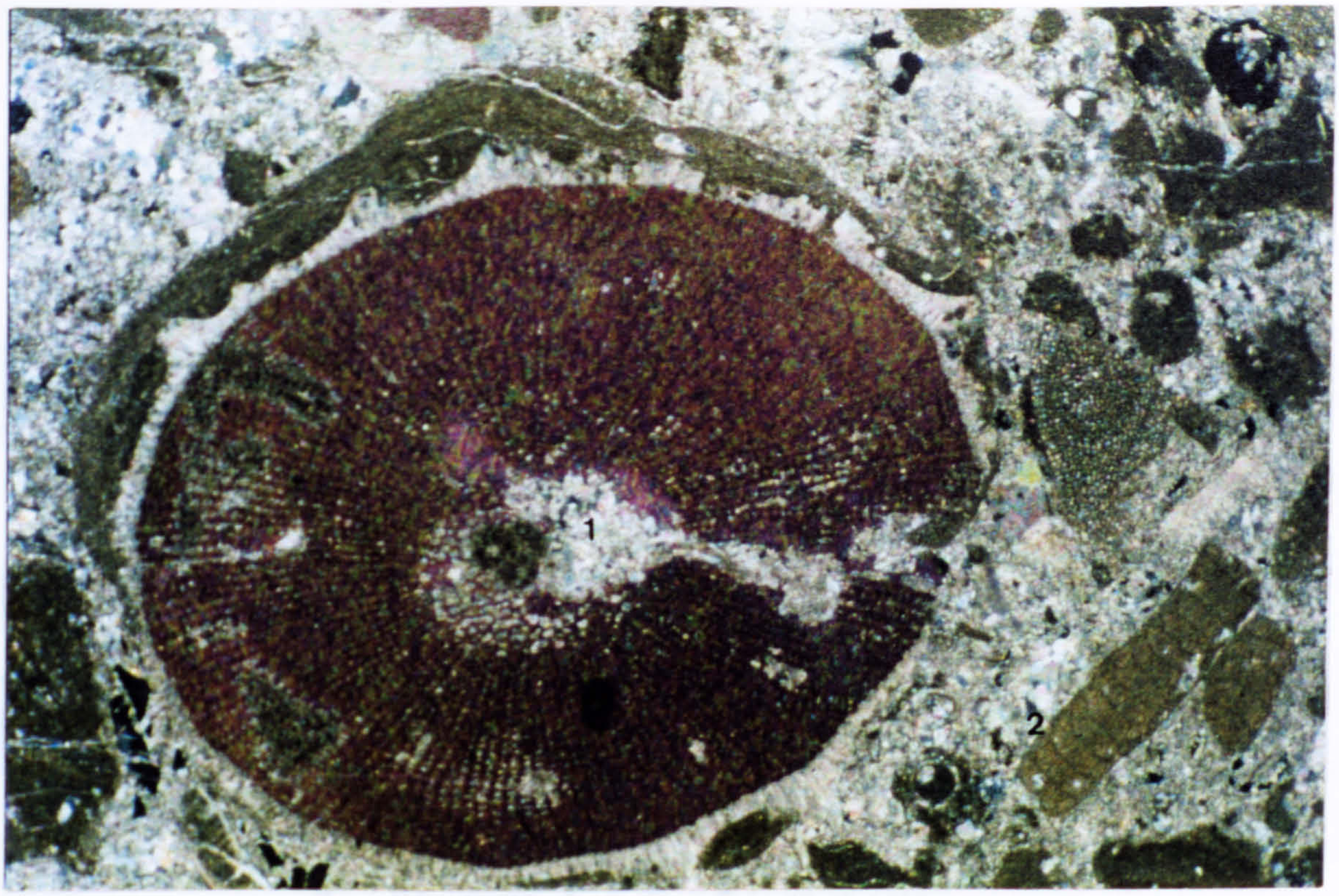



Plate 3.2.3.3a. Tahwah Formation. Unit N, sample WME240. Packstone with *Amphistegina* (1). Late Eocene.


Plate 3.2.3.3b. Tahwah Formation. Unit N, sample WME240. Foraminiferal wackestone contains *Spiroclypeus* (1), branching red algae (2) and small rotaliids (3). Late Eocene.




Pl. 3.2.3.3c Tahwah Formation. Unit N, sample WME240. Wackestone with echinoid plate (1) and Red algae (2). Late Eocene.


Pl. 3.2.3.3d Tahwah Formation. Unit N, sample WME238. Planktonic foraminiferal wackestone, *Globigerina* (1). Late Eocene.

# *Chapter Four*

# *Planktonic Foraminifera*

# *Chapter Four*

# SYSTEMATIC PALAEONTOLOGY

# PLANKTONIC FORAMINIFERA

## 4.1 DESCRIPTIVE TERMINOLOGY

The purpose of this section is to standardise, define and explain the descriptive terminology used in the systematic palaeontology of the planktonic Foraminifera of Oman.

"Identification of the planktonic Foraminifera involved the following procedures.
First of all, the various species, once isolated, were compared to the Palaeogene plankton illustrated in Postuma (1964, 1971) Stainforth *et al.* (1975), Toumarkine and Luterbacher (1985) and the Ellis and Messina *Catalogue of Foraminifera* (1940 etc).

Somewhat later, several visits were made to The Natural History Museum, London, to check them against the collections of Blow, 1979, Samanta 1973 and El-Naggar 1966. Finally, the provisional identifications were then discussed with one of my supervisors, Professor Haynes, before allotting a final name.

All the planktonic foraminiferal identifications are based on matrix-free material. In the Abat Formation (Upper Palaeocene planktonic foraminifera were commonly seen in thin section (see Plate 3.2.1.1a), but at this stage it was felt unwise to attempt to identify them. In many cases in the literature plankton have been mis-identified and I was advised by (Dr. J. Whittaker, pers. comm. 1997) that this was a task for a specialist with many years experience."

### External Morphology

***Test size:*** Test size is here defined in terms of the diameter of the test and may be expressed as follows:

| ***Diameter*** | ***Size*** |
|---|---|
| <0.30mm | Small |
| 0.30-0.40mm | Medium |
| >0.40mm | Large |

***Test shape:*** Coiling in this group is trochospiral with test shapes varying from planoconvex, biconvex, spherical, oval and depressed to compressed. The ratio of the diameter to height is often used as an additional indication of the test shape. The type of test periphery can be rounded, acute, lobate, quadrate and subangular and may have a keel. Keels may be described as faint, narrow, distinct, nodose, well-developed, spiny and spinose to thick.

***Chambers:*** The number of the chambers in the last whorl ranges from a minimum of 3 to a maximum of 8. In addition the following chamber shapes are distinguished: angular, as in *Morozovella abundocamerata, M. aequa, M. aragonenesis, M. crater, M. formosa formosa* and *M. gracilis;* subglobular, as in *M. bolivariana*; conical, as in *M. caucasica;* inflate d, as in *M. centralis, Globigerinatheka barri* and *Truncorotaloides topilensis*; triangular, as in *Morozovella edgari;* crescentic as in *M. pusilla mediterranica*; semilunate, as in *Morozovella* sp. A; subspherical, as in *Acarinina esnaensis*; elongate, as in *A. soldadoensis*; inflate d, as in *Acarinina* sp.; globular, as in *Subbotina triloculinoides, Globigerinatheka curryi* and *Globigerinatheka subconglobata subconglobata*; spherical, as in *Subbotina triangularis* and *Globigerinatheka euganea*; sub-angular, as in *Truncorotaloides libyaensis.*

***Sutures:*** These define the junctions between the chambers and vary from radial; as in *Morozovella abundocamerata, M. caucasica* and *Truncorotaloides libyaensis,* to curved; as in most species of planktonic Foraminifera. They may also be incised; as in *Subbotina triloculinoides* and *Globigerinatheka curryi,* or simply depressed; as in *Acarinina esnaensis.*

***Umbilicus:*** This feature can be used to differentiate between species according to whether it is open; as in *Morozovella abundocamerata, M. angulata* and *Acarinina soldadoensis,* wide; as in *Morozovella acuta, M. caucasica* and *Truncorotaloides libyaensis,* narrow; as in *Morozovella aragonensis* and *Truncorotaloides topilensis,* or shallow; as in *Morozovella occlusa, Subbotina triangularis* and *Turborotalia blowcentralis nom. nov.*

*Aperture:* The position and type of aperture is very important for species identification, especially whether it is a high or a low arch as in most *Morozovella* species (such as *M. aequa, Acarinina pentacamerata* and *Truncorotaloides libyaensis*), and whether it has a lip.

**4.2 FORMAT OF SYSTEMATIC PALAEONTOLOGY:**

*Synonymies:* The synonymy is restricted to the original description and the best illustrated and comparable secondary references. First references are based mainly on the *Ellis and Messina Catalogue*. For secondary references the main sources were Stainforth *et al.,* 1975, Postuma (1971) and more recent publications. References included under the subheading "Geographic distribution" therefore include some that are not part of synonymy. Other references not mentioned in the synonymy are those which although accepted by other authors, are not well illustrated and therefore unverifiable.

*Material:* Species descriptions as far as possible, are based on populations from single samples (where material is rare the actual number of specimens is given). Preservation of the species and the sample number are also noted.

*Description:* All descriptions are written in a standardised form, with test size and shape mentioned first, followed by the nature of the periphery, with its outline (noting that the gradual development of a keel may occur in one individual). Chamber number and shape on both spiral and umbilical sides are recorded with type of sutures described. The character of the umbilicus is noted together with aperture position and shape. Finally the surface ornamentation is described, noting that it is subject to the state of preservation

*Remarks:* This section is used to draw attention to the differences between morphologically similar species and to discuss taxonomic and nomenclatural problems. Also discussed is the stratigraphic range where it differs from published records.

*Geographical distribution and stratigraphical range:* This lists the principal previous records and forms the basis for a discussion of the geographic distribution of the Oman planktonic Foraminifera. All zones quoted (unless otherwise stated) are from Blow (1969; 1979) and Berggren *et al.* (1988) respectively, summaries of these zonations are given in figures 6.1 and 6.2 in Chapter 6.

***Local range and faunal associations:*** This section is used to list microfossils found in association with the cited species in Oman. The list is generally restricted to co-occurring planktonic Foraminifera though where relevant, selected larger Foraminifera are also noted.

| | | |
|---|---|---|
| **CLASS** | **FORAMINIFERA** | **Lee, 1990** |
| **ORDER** | **GLOBIGERINIDA** | **Lankester, 1885** |
| **FAMILY** | **GLOBOROTALIDAE** | **Cushman, 1927** |

**Genus *Morozovella* McGowran in Luterbacher, 1964**

Test trochospirally coiled, periphery carinate, chambers angular, rhomboid or angular-conical; sutures may be thickened, depressed to elevated; wall calcareous, finely perforate, but with nonporous keel or peripheral band, surface smooth to cancellate or hispid; aperture interiomarginal, an extraumbilical-umbilical arch bordered by lip, varying from narrow rim to broad spatulate or triangular flap (Fig. 4.1). Ranging from Lower Palaeocene (Danian), [base of *Morozovella pseudobulloides* Zone (P1)] to Middle Eocene.

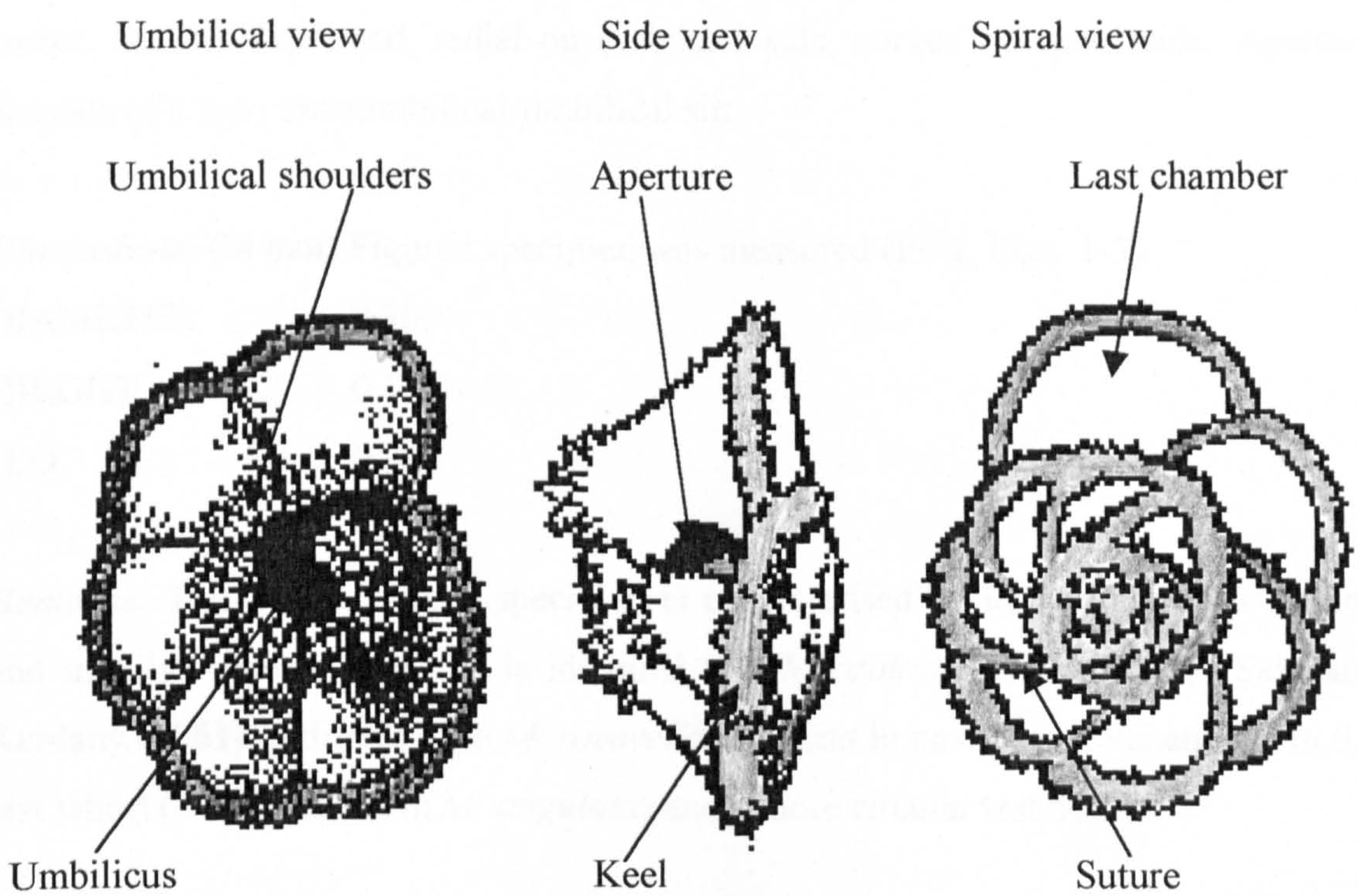



**Fig. 4.1 Morphology of *Morozovella* (Modified from Banner ,1982)**

TYPE SPECIES *Pulvinulina velascoensis* Cushman, 1925

***Morozovella abundocamerata* (Bolli, 1957)**

Pl. 1, Figs.1-3

*Synonymy: Globorotalia angulata abundocamerata* Bolli 1957a, p. 74, Pl. 17, Figs. 4-6. - BOLLI and CITA 1960b, p. 19-20, Pl. 33, Figs. 6a-c.- EL-NAGGAR 1966, p. 194-197, Pl. 22, Figs. 2a-c.

*Globorotalia convexa sensu* SAID and KERDANY 1961, p. 329, Pl. 1, Figs. 7a-c.

*Material:* Three specimens in samples WME-86 and WME-88.

*Description*: Test medium sized, low trochospiral. Periphery circular, slightly lobate, subacute with beaded keel in the early stage which diminishes in strength towards the last chamber. Umbilical surface covered with fine spines at the margin which coarsen towards the umbilical shoulders, whilst fine perforations dominate on the spiral side. There are 6-7 subangular chambers, which increase very slowly in size towards the last whorl. Umbilical side strongly convex, spiral side flat to slightly convex at the center. Sutures depressed, radial on umbilical side, curved on spiral side. Aperture consists of a low, extraumbilical-umbilical slit.

*Dimensions:* (in mm) Figured specimen was measured (Pl. 1, Figs. 1-3).

| | |
|---|---|
| DIAMETER | 0.30 |
| HIEGHT | 0.17 |
| H/D | 0.56 |

*Remarks:* The Omani figured specimen is characterised by its large circular outline and umbilico-convex test and is identical to *Globorotalia convexa* sensu Said and Kerdany (1961). It differs from *Morozovella angulata* in having more chambers in the last whorl (6-7 chambers in *M. angulata*) and a more circular test outline.

*Geographical distribution and stratigraphical range: Morozovella abundocamerata* was originally described by Bolli (1957a) from the Palaeocene of Trinidad where it ranges throughout the *Globorotalia angulata* Zone and into the lower part of the *Globorotalia pseudomenardii* Zone. Bolli and Cita (1960a) recorded the species from the Palaeocene of northern Italy, where its range was wrongly considered as Danian, although the rest of the planktonic Foraminifera indicated a late Palaeocene (Thanetian) age. It has also been recorded from the Middle Palaeocene of Egypt

(Nakkady 1959, Said and Kerdany 1961, and El-Naggar 1966) in association with *G. angulata angulata* at the very top of the *G. velascoensis* Zone.

***Local range and faunal association***: *Morozovella abundocamerata* was previously unknown from Oman. In the Wadi Musawa section of the SE Oman Mountains it occurs with *Morozovella abundocamerata, Morozovella aragonensis, Morozovella caucasica, M. centralis, M. marginodentat, Acarinina esnaensis, A. aspensis, A. soldadoensis, Globigerinatheka subconglobata subconglobata* indicating an early Eocene age within the *Morozovella aragonensis* Zone (P8), which is equivalent to P8 of Blow (1969; 1979) and Berggren *et al.* (1988).

***Morozovella acuta*** **(Toulmin, 1941)**

Pl.1, Figs.4-12

***Synonymy:*** *Globorotalia wilcoxensis* Cushman and Ponton var. *acuta* Toulmin 1941, p. 608, Pl. 82, Figs. 6-8.

*Globorotalia acuta* Toulmin - LOEBLICH and TAPPAN, 1957, p. 185-186, Pl. 47, Figs. 5a-c, Pl. 55, Figs. 4a-5c, Pl. 58, Figs. 5a-c. - EL-NAGGAR 1966, p. 188 -190, Pl. 19, Figs. 5 a-c ; Pl. 20, Figs. 1a-d. – LUTERBACHER 1964, p. 686, Figs. 101-104. - SAMANTA 1970, p. 615-617, Pl. 97, Figs. 1,2. - SAMANTA 1973, p. 450, Pl. 10, Figs. 8-10. STAINFORTH *et al.*, 1975, p. 163-164, Fig. 30, nos. 1-6a-c.

*Morozovella acuta* (Toulmin)- BERGGREN, 1977, p.234.- BERGGREN and NORRIS 1997, p. 82, 84, 86, Pl. 15, Figs. 15, 19-21. *cum syn.*

***Material:*** Eight specimens from samples WM-1, WM-7 and WM-22.

***Description:*** Test large, plano-convex with an acute to subacute periphery and narrow keel. Four to five chambers are present in the last whorl which increase slowly in size as each whorl is added. Umbilical side strongly convex with spiral side almost flat to slightly convex. Wide, deep, open umbilicus. Sutures on spiral side are curved, whilst on umbilical side they are depressed. Aperture consists of a low arch. Bars well-developed on umbilical shoulders.

***Dimensions:*** (in mm) Measurements based on the three figured specimens (Pl. 1, Figs. 4-12).

| | MAXIMUM | MINIMUM | AVERAGE |
|---|---|---|---|
| DIAMETER | 0.42 | 0.34 | 0.38 |
| HEIGHT | 0.22 | 0.20 | 0.21 |
| H/D | 0.52 | 0.58 | 0.55 |

***Remarks:*** The most distinctive feature of this species is the presence of bars on the umbilical shoulders and the acute test periphery. The species differs from *M. velascoensis* in having fewer chambers (*M. velascoensis* has 5 to 8) in the last whorl and better-developed bars. The Omani *M. velascoensis* shows a greater range of morphological variation than previously recorded with some specimens tending towards *M. acuta*. According to the original diagnosis of Cushman (1925b: Pl. 3, Fig. 5a-c) the test shape in *M. velascoensis* is more convex and the umbilicus is wider, more open and has stronger ornamentation than in *M. acuta*.

***Geographical distribution and stratigraphical range:*** Originally described from the Salt Mountain Limestone of Alabama by Toulmin (1941; Pl. 82, Figs. 6-8) where it was believed to be Lower Eocene. Late r Loeblich and Tappan (1957) reassigned *Morozovella acuta* to the Upper Palaeocene. *M. acuta* ranges from the top of the *G. pusilla pusilla* Zone to within the *G. subbotinae* zone and is known from Trinidad (Cushman and Renz, 1942), Gulf and Atlantic Coastal Plains (Cushman, 1944; Shifflett, 1948 and Loeblich and Tappan, 1957), Cuba (Cushman and Bermudez, 1949), Carribean region and Middle East (Grimsdale, 1951), Mid-Pacific seamounts (Hamilton, 1953), Puerto Rico (Pessagno,1960) and Egypt (El-Naggar, 1966). The species is very common in the Upper Palaeocene part of the Pondicherry Formation of southern India (Samanta, 1970). Samanta (1973) also reported this species from the Rakhi Nala Section of Pakistan where it occurs in the *G. velascoensis* and *G. aequa* zones.

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella acuta* is found in the Wadi Musawa section SE Oman Mountains in association with *Subbotina triloculinoides, Morozovella nicoli Morozovella angulata, Morozovella* *pusilla mediterranica,* and *Morozovella velascoensis* indicating a late Palaeocene age within *Morozovella acuta* zone P4 (local expression of the standard zone), and it ranges into *Morozovella velascoensis* Zone, which is equivalent to P5 of Blow (1969; 1979) and Berggren *et al.* (1988).

***Morozovella aequa*** **(Cushman and Renz, 1942)**

Pl. 2, Figs.1-3

***Synonymy:*** *Globorotalia crassata* Cushman var. *aequa* Cushman and Renz 1942, p. 12, Pl. 3, Figs. 3a-c.

*Globorotalia aequa* Cushman and Renz - SAMANTA 1970, p. 617, Pl. 96, Figs. 5, 11-14.-POSTUMA 1971, p. 168, Figs. on p. 169.-STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 163, 164, Fig. 31, nos. 1a-c.

*Morozovella aequa* (Cushman and Renz) BERGGREN, 1977, p. 228-230. - BERGGREN and NORRIS 1997, p. 90, 92, 94, Pl. 16, Figs. 22-24. *cum syn.*

***Material:*** Ten specimens in sample WME-99.

***Description:*** Test small, low trochospiral, umbilico-convex. Periphery acute with fine distinct slightly nodose keel. Test surface covered by spines or nodose ornament, with fine perforations. There are 4-4.5 angular, slightly conical chambers which increase rapidly in size within the last whorl. The last-formed chamber is elongate and occupies one third of the last whorl. Umbilical side strongly convex with narrow, deep, open umbilicus. Spiral side flat to slightly convex. Sutures depressed, radial, on spiral side and strongly curved on umbilical side. Aperture comprises a low arch surrounded by a faint lip and is extraumbilical-umbilical.

***Dimensions:*** (in mm) Figured specimen was measured (Pl. 2, Figs. 1-3).

| | |
|---|---|
| DIAMETER | 0.23 |
| HEIGHT | 0.11 |
| H/D | 0.48 |

***Remarks:*** The Oman specimens closely resemble some of those figured by Cushman and Renz (1942), by Cushman and Bermudez (1949; Pl. 7, Figs. 7-9) and Luterbacher (1964; p. 669, Text-Figs. 65a-c - 66a-c, p. 672, Fig. 71a-c). However, it differs slightly from the type specimen of Cushman and Renz (1942; Pl. 3, Figs. 1a-c) in having a more rounded test. *Morozovella aequa* differs from *M. acuta, M. velascoensis* and *M. angulata* in that it is less lobate, has a narrower umbilicus, and has fewer chambers in the last whorl i.e (4-4.5 chambers). It is also more tightly coiled.

***Geographical distribution and stratigraphical range:*** *Morozovella aequa* was first described by Cushman and Renz (1942) from the Soldado formation of Trinidad to which they assigned an Eocene age. Bolli (1957a) assigned *Morozovella aequa* to his *Globorotalia velascoensis* Zone and concluded that *M. aequa* ranged from the base of his *G. pseudomenardii* Zone to the top of the *G. rex* Zone. Loeblich and Tappan (1957) reported this species from the Upper Palaeocene-Lower Eocene of the Lizard Springs Formation of Trinidad and the Gulf and Atlantic Coastal Plains of the USA. El-Naggar (1966) reported *M. aequa* from the Palaeocene-Lower Eocene of the Esna-Idfu region of Egypt. Samanta (1970) reported the species from the Upper Palaeocene of the Pondicherry Formation of southern India. Samanta (1973) also described the species from the Rakhi Nala section of Pakistan where he assigned it to the *Globorotalia angulata* and *Globorotalia formosa formosa* Zones. Hamam and Haynes (1977) recorded the species from the Abu El Awafi section of Jordan, where it commonly occurs in the *Globorotalia subbotinae* zone.

***Local range and faunal associations:*** *Morozovella aequa* has not been recorded previously from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella caucasica, M. formosa, M. gracilis, Acarinina pentacamerata, M. marginodentata, M. subbotinae, M. crater* and *M.* sp. C indicating an early Eocene age within the *Acarinina pentacamerata* Zone (P9), which is equivalent to the P9 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Morozovella angulata*** **(White,1928)**

Pl. 2, Figs. 4-6, Pl. 15, Figs. 3-5

***Synonymy:*** *Globigerina angulata* White 1928, p.191-192, Pl. 27, Figs. 13a-c.
*Globorotalia angulata* (White) BOLLI 1957a, p. 74, Pl. 17, Figs. 10-12.- LOEBLICH and TAPPAN 1957, p. 187, Pl. 45, Figs. 7a-c, Pl. 48, Figs. 2a-c, Pl. 55, Figs. 6a-c, 7a-c, Pl. 64, Figs. 5a-c.- SAID and SABRY 1964, p.382, Pl. 1, Figs. 3a-c. – POSTUMA 1971, p. 170, Figs. on p. 171. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 167,168, Fig. 34, nos. 7a-c. – TOUMARKINE and LUTERBACHER 1985, p. 111, Fig. 14, nos. 5a-c.
*Morozovella angulata* (White) BERGGREN, 1977, p. 230-232. - BERGGREN and NORRIS 1997, p. 70-72, Pl. 14, Figs. 2,3,9,14,18,20-23. *cum syn.*

***Material:*** Seven specimens in samples WM-1 and WM-7.

***Description:*** Test of medium size, very low trochospiral. Periphery subacute, lobate with faint keel. Test surface covered with fine spines except on the umbilical shoulders. There are 5-7 angular to subangular chambers increasing moderately in size with each chamber addition in the last whorl (doubling). Umbilical side strongly convex, spiral side almost flat to slightly convex. Shallow to deep, narrow, open umbilicus. Sutures on umbilical side radial and depressed, whilst on spiral side they are strongly curved and slightly depressed. Aperture consists of a low arch and is extraumbilical-umbilical with a faint lip. The last chamber occupies one quarter of the last whorl.

***Dimensions:*** (in mm) Based on figured specimen (Pl. 2, Figs. 4-6 and Pl. 15, Figs. 3-5).

| | Maximum | Minimum | Average |
|---|---|---|---|
| DIAMETER | 0.31 | 0.29 | 0.30 |
| HIEGHT | 0.17 | 0.15 | 0.16 |
| H/D | 0.55 | 0.51 | 0.53 |

***Remarks:*** This species is characterised by its lobate periphery with faint keel and by its angular to conical chambers in the last whorl. The Oman specimens resemble those of Leonov and Alimarina (1961, Pl. 4, text-Fig. 1a-c, 2a-c, Pl. 5, text-Fig. 5a-c). They differ slightly from the type specimens of White (1928) and the specimens of El-Naggar (1966, Pl. 22, Figs. 1a-c) in having a more conical umbilical side, however they show close similarities in the two other views. *Morozovella angulata* differs from *M. aequa* in being more lobate and less tightly coiled, with more chambers (5 to 7) in the last whorl.

***Geographical distribution and stratigraphical range:*** *Morozovella angulata* was originally described from the Palaeocene Velasco Shale Formation of Mexico by White (1928). Hay (1960) stated that the *M. angulata* ranges from the upper part of the *G. uncinata* Subzone to the top of the *G. velascoensis* Zone. Loeblich and Tappan (1957) described *M. angulata* from the Palaeocene of the Gulf and Atlantic Coastal Plains of USA. Bolli (1957b) recorded it from the Palaeocene of Trinidad and concluded that it ranged from the upper part of the *G. uncinata* Zone to the top of the *G. pusilla pusilla* Zone. Samanta (1970) recorded *G. angulata* from the Palaeocene Pondicherry Formation of southern India.

***Local range and faunal associations:*** *Morozovella angulata* was previously unknown from Oman. Found in the Wadi Musawa section of SE Oman Mountains in association with *Morozovella acuta, M. nicoli M. pusilla mediterranica M. velascoensis* and *Subbotina triloculinoides* indicating a late Palaeocene age within *Morozovella acuta* Zone (P4) local expression of the standard zone.

***Morozovella aragonensis* (Nuttall, 1930)**

Pl..2, Figs. 7-12, Pl. 15, Figs. 6-8

***Synonymy:*** *Globorotalia aragonensis* Nuttall 1930, p. 288, Pl. 24, Figs. 6-11. - GLAESSNER 1937, p.48, Pl. 1, Figs. 5a-c.- SUBBOTINA 1953, p. 215-216, Pl. 18, Figs. 6-7. - HAQUE 1956, p. 180, Pl. 4, Figs. 4a-c.- BOLLI 1957, p. 75.- LUTERBACHER 1964, p. 696, Figs. 121-123.- SAMANTA 1973, p.451, Pl. 8, Figs. 4-6.– STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p.

168, 169, Fig. 35, nos. 3-5.

*Morozovella aragonensis* (Nuttall) BERGGREN, 1977, p.244.

***Material:*** Twelve specimens in samples WM-35, WME-86 and WME-95.

***Description:*** Test medium sized, umbilico-convex, low trochospiral. Periphery circular, rounded, acute with well-ornamented keel. There are 5-6 angular chambers which increase slowly in size as added in the last whorl. Umbilical side strongly convex and ornamented with short spines, spiral side flat. Sutures on umbilical side depressed, radial; on spiral side curved and slightly raised. Aperture low arch, extraumbilical-umbilical with faint lip.

***Dimensions:*** (In mm) Figured specimens measured (Pl. 2, Figs. 7-12 and Pl. 15, Figs. 6-8).

| | Maximum | Minimum | Average |
|---|---|---|---|
| DIAMETER | 0.45 | 0.31 | 0.38 |
| HEIGHT | 0.28 | 0.15 | 0.29 |
| H/D | 0.62 | 0.48 | 0.55 |

***Remarks:*** The Oman specimens have a distinctive circular outline and thick rugose wall. *M. aragonensis* can be confused with *M. velascoensis* but the former has a smaller umbilicus, fewer chambers (5 to 6) in the last whorl and a more rounded test. The Oman material compares well with Cuban representatives of the species (Cushman and Bermudez, 1949, p. 38-39, Pl. 7, Figs. 13-15) and differs slightly from the type specimen of Nuttall, (1930) in having fewer chambers in the last whorl (5 chambers in the type).

***Geographical distribution and stratigraphical range:*** *Morozovella aragonensis* was originally described from the Middle Eocene Aragon Formation of eastern Mexico by Nuttall (1930). According to Bolli (1957) it ranges from the Lower Eocene *G. formosa formosa* Zone to the Middle Eocene *Globigerinatheka subconglobata* Zone. Samanta (1973) reported *M. aragonensis* from the *G. formosa formosa* and *G. esnaensis* zones

***Local range and faunal associations:*** *Morozovella aragonensis* was previously unknown from Oman. Found in Wadi Musawa, SE Oman Mountains in association with *M. marginodentata M. abundocamerata, M. centralis, M. marginodentata, M. caucasica, M.* sp. A, *Subbotina quadrata, Globigerinatheka subconglobata subconglobata , Subbotina triangularis, Acarinina esnaensis, A. aspensis, and A. soldadoensis* indicating an early Eocene age. *Morozovella aragonensis* found within *Morozovella aragonensis* Zone P8 in this study, which is equivalent to P8 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Morozovella bolivariana* (Petters, 1954)**

Pl. 3, Figs.1-3

***Synonymy:*** *Globigerina wilsoni* Cole subsp. *bolivariana* Petters 1954, p.39, Pl. 8, Figs. 9a-c.

***Material:*** Two specimens in sample WME-186.

***Description:*** Test medium sized, umbilico-convex, low trochospiral. Periphery broadly rounded and slightly lobate. Test surface finely perforate, with spines developed on umbilical shoulders. There are 4-4.5 subglobular chambers which increase moderately in size as each is added in the last whorl giving a quadriangular outline. Umbilical side convex, spiral side flat to slightly raised at the center. Open narrow umbilicus. Umbilical sutures depressed, radial; spiral sutures depressed and slightly curved. Aperture narrow, extraumbilical-umbilical slit which extends towards the spiral side and is bordered by a lip.

***Dimensions:*** (in mm) Based on figured and described specimen (Pl. 3, Figs. 1-3).

| | |
|---|---|
| DIAMETER | 0.36 |
| HEIGHT | 0.23 |
| H/D | 0.63 |

***Remarks:*** The Oman specimens are identical to those described by Petters (1954).

*Morozovella bolivariana* differs from *M. centralis* in having five chambers in the last whorl instead four as in *M. centralis.*

***Geographical distribution and stratigraphical range:*** *Morozovella bolivariana* was originally described by Petters (1954) from the presumed Lower Cretaceous of Columbia.

***Local range and faunal associations:*** *Morozovella bolivariana* has not been previously recorded from Oman. Found in the Wadi Musawa section of the Southeast Oman Mountains in association with *Truncorotaloides libyaensis, Truncorotaloides topilensis, Globigerinatheka curryi* and *Globigerinatheka* sp. B, indicating Middle Eocene age within the *Truncorotaloides libyaensis/Morozovella bolivariana* Zone (P13) on the basis of local range.

**_Morozovella caucasica_ (Glaessner, 1937)**

Pl. 3, Figs.4-12, Pl. 4, Figs. 1-6

***Synonymy:*** *Globorotalia aragonensis* Nuttall var. *caucasica* Glaessner 1937, p. 31, Pl. 1, Fig. 6.

*Globorotalia caucasica* Glaessner - LUTERBACHER 1964, p.684, Pl. 1, Fig. 97. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 175-176, Fig. 41, nos. 1a-c, 2a-c, 3-6.

*Globorotalia (Morozovella) crater caucasica* Glaessner. JENKINS 1971, p. 103, Pl. 8, Figs. 189-191.

*Morozovella caucasica* (Glaessner) BERGGREN, 1977, p. 245, 246.

***Material:*** Abundant in samples WME-76, WME-86, WME-88 and WME-98.

***Description:*** Test large, trochospiral, umbilico-convex (last chamber broken in figured and described specimen in Pl. 4, Figs.1-3). Periphery acute with distinct and well-developed keel. Test surface heavily ornamented with spines. There are 6-8 conical chambers which increase regularly and slowly in size as added in the last whorl. However, the last chamber is distinctively smaller (kummerform). Umbilical side strongly convex, spiral side flat. Umbilical sutures radial, depressed; spiral sutures raised. Aperture consists of a low extraumbilical-umbilical arch with a distinct lip.

***Dimensions:*** (in mm) Based on five figured and described specimens (Pl. 3, Figs. 4-12 and Pl. 4, Figs. 1-6).

| | MAXIMUM | MINIMUM | AVERAGE |
|---|---|---|---|
| DIAMETER | 0.51 | 0.35 | 0.43 |
| HEIGHT | 0.27 | 0.15 | 0.21 |
| H/D | 0.53 | 0.43 | 0.48 |

***Variation:*** In the original description of *Morozovella caucasica* by Glaessner (1937), most specimens show distinctive umbilical shoulders and a strong keel. The umbilicus varies from narrow to wide and from shallow to deep. The number of chambers varies from 5-8 whilst the umbilical side can vary from conical to flattened (Pl. 2, Figs. 2,5,8,11,14). Surface ornamentation on both sides of the test varies from beaded to spinose with coarse perforation. The spiral side varies from almost flat to slightly convex with raised to lobate sutures. A number of specimens also show a stunted last chamber (kummerforms).

***Remarks:*** The Oman material shows little variation from *Morozovella caucasica* as originally described by Glaessner (1937). The Omani specimens are similar to *Morozovella crater caucasica* described by Jenkins (1971) which differ from *M. crater* in having more chambers in the last whorl (6 to 8 chambers). This species is often confused with *Morozovella velascoensis.* However, *M. caucasica* has coarser ornamentation and more chambers than *Morozovella velascoensis* and is crown-shape in peripheral view (see Pl. 3, Figs. 4-12; Pl. 8, Figs. 7-12) for comparison).

***Geographical distribution and stratigraphical range:*** *Morozovella caucasica* was originally described from the Lower Eocene of the Caucasus by Glaessner (1937). Jenkins (1971) reported the species from the Lower Eocene *G. crater crater* Zone of New Zealand.

***Local range and faunal associations:*** *Morozovella caucasica* was previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella aragonensis, M. marginodentata, Morozovella abundocamerata Subbotina quadrata, Subbotina triangularis*. *Globigerinatheka subconglobata subconglobata* indicating an early Eocene age. It ranges from *Morozovella aragonensis* P8 through *Acarinina pentacamerata* Zone P9 equivalent to P8 and P9 of Blow (1969, 1979) and Berggren *et al.* (1988).

*Morozovella centralis* **(Cushman and Bermudez, 1937)**

Pl. 13, Figs.1-3

***Synonymy:*** *Globorotalia centralis* Cushman and Bermudez 1937, p. 26, Pl. 2, Figs. 62-65.- SAMANTA 1969, p. 333, Pl. 2, Figs. 2a-c.-POSTUMA 1971, p. 182, text-Figs. on p. 182.- TOUMARKINE and LUTERBACHER 1985, p.136, Fig. 34, nos. 5-8.

***Material:*** Six specimens in sample WME-76.

***Description:*** Test medium sized, low trochospiral. Periphery almost rounded, with circular to subangular outline, slightly lobate. Test surface smooth and distinctly perforate. There are 4 inflate d chambers, which increase fairly rapidly in size as added in the last whorl. Umbilical side distinctly convex, spiral side almost flat to slightly convex. Sutures on umbilical side radial, depressed; on spiral side curved, strongly oblique, nearly straight. Umbilicus narrow. Aperture a large elongate arch extending from the umbilicus to the periphery.

***Dimensions:*** (in mm). The figured specimen was measured (Pl. 13, Figs. 1-3).

| | |
|---|---|
| DIAMETER | 0.36 |
| HEIGHT | 0.34 |
| H/D | 0.94 |

***Remarks:*** The Oman specimens are very similar to those described and illustrated by

Samanta (1969, p. 333, Pl. 2, Figs. 2a-c). They differ slightly from those described by Bolli *et al.*, (1957) in having a flat spiral side and elongate chambers in the last whorl. *Morozovella centralis* differs from *Morozovella. cerroazulensis* in having a more angular late ral outline and more inflate d spiral side.

***Geographical distribution and stratigraphical range:*** *Morozovella centralis* was originally described by Cushman and Bermudez (1937) from the lower part of the Upper Eocene of Cuba. Also recorded from Cuba by Postuma (1971) and Toumarkine and Luterbacher (1985). Samanta (1969) recorded the species from the Middle to Upper Eocene of the Garo Hills, India. Late r Samanta (1970) found *Morozovella centralis* in the *Orbulinoides beckmanni* and *Truncorotaloides rohri* zones at Lakhapot western India indicating a Middle Eocene age. According to Samanta (1973) *M. centralis* occurs in the *G. crassata/Truncorotaloides topilensis* and *Truncorotaloides rohri* Zones in the Rakhi Nala section of Pakistan, indicating a Middle Eocene age.

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella centralis* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Subbotina triangularis, Morozovella caucasica, M. aragonensis, and M. marginodentata* indicating an early Eocene age within *Morozovella aragonensis* Zone (P8). However, this zone is equivalent to P8 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Morozovella crater* (Finlay, 1939)**

Pl. 4, Figs.7-9

***Synonymy:*** *Globorotalia crater* Finlay 1939, p.69(1): 25. - HORNIBROOK 1958, p33, Pl. 1, Figs. 3-5. - JENKINS 1971, p.103, Pl. 8, Figs. 192-197.

***Material:*** Two specimens in sample WME-103.

***Description:*** Test medium sized, trochospiral, conical. Periphery subangular with a well-developed keel and small spinose projections. Test surface covered with small spines which coarsen towards the umbilical chamber shoulders. There are 5 angular to conical chambers which increase slowly in size as added in the last whorl. Umbilical side strongly convex with well-developed umbilical shoulders, spiral side almost flat to slightly convex. Sutures radial, depressed to slightly curved on umbilical side, and beaded on spiral side. Aperture comprises a low arch, which is interiomarginal, extraumbilical-umbilical. Umbilicus narrow and shallow to slightly deep.

***Dimensions:*** (in mm) Figured specimen was measured (Pl. 4, Figs. 7-9).

| | |
|---|---|
| DIAMETER | 0.28 |
| HEIGHT | 0.16 |
| H/D | 0.57 |

***Remarks:*** The Oman specimen resembles those of Hornibrook (1958), and Jenkins (1971) but differ slightly from the type specimen of Finlay (1939) in having five chambers in the final whorl instead of four and in being less lobate. *Morozovella crater* differs from *M. caucasica* in having fewer chambers in the last whorl 5 chambers, and in being more tightly coiled.

***Geographical distribution and stratigraphical range:*** *Morozovella crater* is common in New Zealand and was considered by Finlay (1939) to be Middle Eocene though Jenkins (1971) reported it from the Lower Eocene.

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella aequa, M. subbotinae, Morozovella* sp. C in beds considered to be early Eocene age on the basis of the planktonic foraminiferal assemblages from above and below this sample. However, this species is found within *Acarinina pentacamerata* Zone (P9), which is equivalent to (P9) of Blow (1969; 1979), and Berggren *et al.* (1988) respectively.

**_Morozovella edgari_ (Premoli Silva and Bolli, 1973)**

Pl. 4, Figs.10-12

*Synonymy: Globorotalia edgari* Premoli Silva and Bolli 1973, p. 526, Pl. 7, Figs. 10-12, Pl. 8, Figs. 1-2. - ARENILLAS and MOLINA 1996, p. 95, Pl. 3, Figs. 3,4.

*Material:* Three specimens in sample WME-148.

*Description:* Test small, umbilico-convex with thick wall. Periphery lobate, acute with faint keel developed in last two chambers. Test surface covered by pustules concentrated on the umbilical shoulders. There are 4.5-6 triangular chambers which increase gradually in size, but increase rapidly in height in the last whorl. Umbilical side strongly convex, spiral side flat to slightly convex in the inner portion. Umbilical sutures radial and depressed, whilst spiral sutures are curved and flush. Aperture a low arch, umbilical-extraumbilical with imperforate lip. Umbilicus narrow and deep.

*Dimensions:* (in mm) Measurement based on figured specimen (Pl. 4, Figs. 10-12).

| | |
|---|---|
| DIAMETER | 0.28 |
| HEIGHT | 0.19 |
| H/D | 0.68 |

*Remarks:* The Oman specimens compare very well with those illustrated and described by Arenillas and Molina (1996) from southern Spain. *Morozovella edgari* differs from *M. parva* in its smaller size and thinner keel. *M. subbotinae* is larger (0.08mm) with fewer chambers in the last whorl (4 to 5 chambers) and a more lobate peripheral outline than *M. edgari*. Differs from *M. occlusa* Loeblich and Tappan in its smaller size, less convex spiral side and well-developed pustules.

*Geographical distribution and stratigraphical range: Morozovella edgari* was originally described by Premoli Silva and Bolli (1973) from the Lower Eocene of the Caribbean within the *Globorotalia edgari* and *Globorotalia velascoensis* Zones. *M. edgari* was also recorded from the Palaeocene/Eocene boundary of Spain by Arenillas and Molina (1996).

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella edgari* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella edgari, Globigerinatheka eugania, Truncorotaloides topilensis and Turborotalia blowcentralis nom. nov.* in beds considered to be of Middle Eocene age which based on larger Foraminifera *Nummulites maculatus* and *N. shaubi* within *Truncorotaloides topilensis/Morozovella edgari* Zone (P10) on the basis of the local range.

***Morozovella formosa formosa* (Bolli, 1957)**

Pl. 5, Figs.1-3

*Synonymy: Globorotalia formosa formosa* Bolli 1957, p. 76, Pl. 18, Figs. 1-3. - LUTERBACHER 1964, P.694-696. - STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 184-185, Fig. 48, nos. 1-3
*Globorotalia formosa* Bolli. POSTUMA 1971, p. 190-191.
*Morozovella formosa* (Bolli) BERGGREN, 1977, p. 242.

***Material:*** Three specimens in sample WME-94.

***Description:*** Test medium sized, umbilico-convex. Periphery lobate with faint, spiny keel. Test surface covered with spines. There are 5-6 angular chambers in the last whorl which increase slowly in size as each is added. Umbilical side strongly convex covered by coarse spines, spiral side flat, perforate and slightly spinose. Sutures on spiral side raised and curved, whilst umbilical sutures are depressed and radial. Umbilicus open, deep and wide. Aperture a low arch.

***Dimensions:*** (in mm ) The described and figured specimen was measured (Pl. 5, Figs. 1-3).

| | |
|---|---|
| DIAMETER | 0.32 |
| HEIGHT | 0.24 |
| H/D | 0.75 |

***Remarks:*** The Oman specimens compare well with those described and illustrated by Luterbacher (1964; p. 694, Figs. 118a-c-120a-c). *Morozovella formosa formosa* differs from *M. gracilis* in having more chambers in the last whorl (5 to 6 chambers), and in being less lobate. The Oman form differs slightly from the original illustration of Bolli (1957) in having a more lobate outline. The specimens illustrated by Samanta (1973, p. 458, Pl. 9, Figs. 1-3) have a biconvex shape instead of being umbilico-convex.

***Geographical distribution and stratigraphical range:*** *Morozovella formosa formosa* was originally described by Bolli (1957) from the upper part of the Lizard Springs Formation, Trinidad (*Globorotalia formosa formosa* Zone). Luterbacher (1964) recorded it from the *G. rex* Zone to overlying *G. formosa formosa* Zone in Trinidad. Samanta (1970) recorded *Morozovella formosa formosa* from the Palaeocene Pondicherry Formation of southern India and also (Samanta, 1973) reported the species from the Upper Palaeocene to Lower Eocene *G. formosa formosa* Zone of the Rakhi Nala section of Pakistan.

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella formosa formosa* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella, caucasica, M. marginodentata, M. subbottinae, M. crater, M. aequa, A. pentacamerata* indicating an early Eocene age within *Acarinina pentacamerata* Zone P8, which is equivalent to P9 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

### *Morozovella gracilis* (Bolli, 1957)

Pl. 5, Figs.4-6

***Synonymy:*** *Globorotalia formosa gracilis* Bolli 1957, p. 75, Pl. 18, Figs. 4-6. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 184, 186, Fig. 49, nos. 1-3.

*Globorotalia gracilis* Bolli LUTERBACHER 1964, p. 692-694, Figs. 115a-c-117a-c. - SAMANTA 1970, p. 625, Pl. 97, Figs. 13-14. - SAMANTA 1973, p. 458, Pl. 9,

Figs. 1-3. - POSTUMA 1971, P. 192-193.
*Morozovella gracilis* (Bolli) BERGGREN 1977, P. 241, 242. - BERGGREN and NORRIS 1997, p. 100,102, Pl. 16, Figs. 19-20. *cum syn.*

*Material:* Five specimens in sample WME-94.

*Description:* Test low trochospiral, umbilico-convex. Periphery acute, slightly lobate with distinct spinose keel. There are 5-7 angular chambers which increase rapidly in size in the last whorl as added. Umbilical side strongly convex, spiral side flat to slightly convex from the inner portion. Sutures on umbilical side radial, depressed; on spiral side curved, raised and hidden by the rugose surface. Umbilicus deep and narrow. Aperture a low arch with weak lip.

*Dimensions:* (in mm) Figured specimen was measured (Pl. 5, Figs. 4-6).

| | |
|---|---|
| DIAMETER | 0.32 |
| HEIGHT | 0.14 |
| H/D | 0.44 |

*Remarks:* The Oman specimen compares closely with that illustrated and described by Postuma (1971). *Morozovella gracilis* differs from *Morozovella marginodentata* (Subbotina 1953, Pl. 17, Figs. 15-16) in having a well-developed keel. *Morozovella gracilis* also differs from *M. formosa formosa* (Bolli 1957, p. 76, Pl. 18, Figs. 1-3) in having a smaller more biconvex test and stronger keel. However, Hillebrandt (1962) treated *Morozovella gracilis* as a junior synonym of *M. marginodentata.*

*Geographical distribution and stratigraphical range: Morozovella gracilis* was originally described by Bolli (1957) from the early Eocene *Globorotalia subbotinae* Zone of Trinidad. Bolli and Cita (1960a) reported it from the *G. rex* Zone in the Paderno d' Adda section of northern Italy. Luterbacher (1964) gave its range as being from the base of the *G. aequa* Zone to the *G. aragonensis* Zone. Samanta (1970) noted that *Morozovella gracilis* ranged from the *G. pseudomenardii* Zone to the *G. aequa* Zone (Late Palaeocene ) in southern India. Postuma (1971) reported *M. gracilis* as ranging from the *G. rex* Zone to the lower part of the *G. aragonensis* Zone indicating a Lower Eocene age. Samanta (1973) reported the species from the Rakhi Nala section of Pakistan and assigned it to *Globorotalia formosa formosa* Zone (Upper Palaeocene to Lower Eocene).

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella gracilis* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella, caucasica, M. marginodentata, M. subbottinae, M. crater, M. aequa, A. pentacamerata* indicating an early Eocene age within *Acarinina pentacamerata* Zone P8, which is equivalent to P9 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively

***Morozovella marginodentata* (Subbotina, 1953)**

Pl. 5, Figs.7-12, Pl. 6, Figs. 1-3

***Synonymy:*** *Globorotalia marginodentata* Subbotina 1953, p.212-213, Pl. 17, Figs. 14-16, Pl. 18, Figs. 1-3. – SUBBOTINA 1971, p. 268-269, 272, Pl. 17, Figs. 14-16, Pl. 18, Figs. 1-3. - SAMANTA 1973, p. 460, Pl. 11, Figs. 1-3. - HAMAM and HAYNES 1977, Pl. 4, Figs. 5-6. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 203-204, Fig. 65, nos. 1-7.
*Morozovella marginodentata* (Subbotina) BERGGREN, 1977, p. 241.

***Material:*** Eight specimens in samples WME-86, WME-88 and WME-95.

***Description:*** Test biconvex and rounded with convex umbilical side and slightly convex spiral side at the centre. Periphery lobate and acute. Keel well- developed and together with the test surface is covered by coarse spines especially on the spiral side. There are 5-6 chambers which increase rapidly in size as added in the last whorl. Umbilicus deep and narrow. Spiral sutures curved and slightly raised; umbilical sutures depressed. Aperture comprises a low arch with a thick lip.

***Dimensions:*** (in mm) The described specimens were measured (Pl. 5, Figs. 7-12 and Pl. 6, Figs. 1-3).

| | MAXIMUM | MINIMUM | AVERAGE |
|---|---|---|---|
| DIAMETER | 0.37 | 0.28 | 0.32 |
| HEIGHT | 0.18 | 0.15 | 0.16 |
| H/D | 0.48 | 0.53 | 0.49 |

***Remarks:*** The Omani specimens show close similarities to those of Subbotina (1953), but differ slightly from the original specimens in the shape of the umbilical side. The Oman specimens are identical to those described by Hamam and Haynes (1977). *M. marginodentata* differs from *M. subbotinae* and other relate d *Morozovella* species in having a broad keel. The biconvex test and lobate periphery of this species are distinctive.

***Geographical distribution and stratigraphical range:*** *Morozovella marginodentata* was originally described by Subbotina (1953) from the *G. marginodentata* Subzone in the northern Caucasus which he considered to be Lower Eocene. Luterbacher (1964) reported this species from the upper part of the *G. rex* Zone to *G. formosa formosa* Zone of Bolli in Trinidad whilst Hillebrandt (1965) reported *Morozovella marginodentata* from the Upper Palaeocene of northwest Spain. Hay (1960) reported it from the Palaeocene *Globorotalia pseudomenardii* and *Globorotalia velascoensis* Zones of Mexico. It also occurs in the Upper Palaeocene to Lower Eocene of New Zealand (Jenkins, 1966), Lower Eocene of Egypt (Krasheninnikov and Ponikarov, 1965), Upper Palaeocene Pondicherry Formation of southern India (Samanta, 1970) and, Lower Eocene Rakhi Nala section of Pakistan where it ranges from the *Globorotalia aequa* Zone to the *Globorotalia formosa formosa* Zone (Samanta, 1973). Hamam and Haynes (1977) reported it from Upper Palaeocene of Jordan.

***Local range and faunal associations:*** Previously unknown in Oman. *Morozovella marginodentata* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella, caucasica, M. marginodentata, M. subbottinae, M. crater, M. aequa, A. pentacamerata* indicating an early Eocene age. From within *Morozovella aragonensis* Zone P8 through *Acarinina pentacamerata* Zone P8, which are equivalent to P8/P9 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Morozovella nicoli* (Martin, 1943)**

Pl. 6, Figs.4-6

*Synonymy: Globorotalia nicoli* Martin 1943, p. 27, Pl. 7, Figs. 3a-c. - GARTNER and HAY 1963, p. 565, Pl. 2, Figs. 3a-c. - SAMANTA 1970, p. 627, Pl. 95, Figs. 5-6.

*Material:* Seven specimens in sample WM-1.

*Description:* Test small and biconvex. Test periphery is acute with a narrow keel. Test surface is covered by coarse spines. The number of chambers in the last whorl varies from 5-5.5 and these increase slowly in size as added. Spiral side is slightly convex with curved sutures; whilst umbilical side is convex with a narrow, open umbilicus and depressed to slightly curved sutures. Aperture comprises a low arch.

***Dimensions*:** (in mm) Based on described specimen (Pl. 6, Figs. 4-6).

| | |
|---|---|
| DIAMETER | 0.27 |
| HEIGHT | 0.13 |
| H/D | 0.48 |

***Remarks*:** The Oman specimens resemble those of Samanta (1970), and differ only slightly from the original specimens of Martin (1943) in having 5-5.5 chambers in the last whorl instead of 5 chambers. The Omani specimens differ from *Globorotalia convexa* Subbotina (1953) in that the latter is more convex, smaller in size (0.23mm) and has more chambers (6) in the last whorl. *Morozovella nicoli* also differs from the above mentioned species in that its chambers are more strongly elongated in the direction of coiling in spiral view.

***Geographical distribution and stratigraphical range:*** *Morozovella nicoli* was originally described from the Palaeocene to Lower Eocene, Lodo Formation of California by Martin (1943). Olsson (1960) reported *Morozovella nicoli* from the Palaeocene Hornerstown Formation of New Jersey. Gartner and Hay (1962) reported this species from the Ilerdian of France, whilst Samanta (1970) recorded it from the upper marlstone of the Pondicherry Formation southern India which he assigned to the upper part of the Upper Palaeocene. El-Naggar (1966) reported that the *Morozovella nicoli* occurs rarely in the uppermost Palaeocene *G. aequa/G. esnaensis* Subzone in the Esna-Idfu region of Egypt.

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella nicoli* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella acuta M. angulata, M. pusilla mediterranica* and *Subbotina triloculinoides* indicating a late Palaeocene age. This species found within *Morozovella acuta* Zone (P4) local expression of the standard zone.

***Morozovella occlusa* (Loeblich and Tappan, 1957)**

Pl. 6, Figs. 7-9

***Synonymy:*** *Globorotalia occlusa* Loeblich and Tappan 1957, p. 191, Pl. 55, Figs. 3a-c Pl. 64, Figs. 3a-c. – LUTERBACHER 1964, p. 690-692, Figs. 112a-113c. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 208-210, Fig. 70, nos. 1a-c. - SAMANTA 1973, p. 460, Pl. 10, Figs. 11-13.
*Morozovella occlusa* (Loeblich and Tappan) BERGGREN, 1977, p. 234, 235. - BERGGREN and NORRIS 1997, p. 76, 78, Pl.16, Figs. 10-13, 15, 17. *cum syn.*

***Material:*** Rare in sample WM-22.

***Description:*** Test small to medium sized, biconvex, trochospiral. Periphery subcircular to slightly lobate with distinctly well-developed, spinose keel. Thickness of the keel is about 0.04 mm. Test surface strongly ornamented with fine to coarse spines (length from 0.01 to 0.03 mm). There are 5-7 subangular chambers in the last whorl which increase very slowly in size as each chamber is added. Umbilical side convex and characterised by subacute umbilical shoulders with a narrow and shallow open umbilicus. Spiral side slightly convex. Umbilical sutures radial and depressed; spiral sutures curved and slightly raised. Aperture consists of a low arch and is extraumbilical-umbilical.

***Dimensions:*** (in mm) Based on figured specimen (Pl. 6 Figs. 7-9).

| | |
|---|---|
| DIAMETER | 0.38 |
| HEIGHT | 0.20 |
| H/D | 0.53 |

***Remarks:*** The Omani specimens show all the distinctive features of *M. occlusa* using the species concept of Gohrbandt (1963) and Samanta (1973) and are identical to those described by Gohrbandt (1963: Pl. 4, Figs. 16-18; Pl. 5, Figs. 1-3). The Oman specimens differ slightly from those of Loeblich and Tappan (1957) and Samanta (1973) in having a more rounded test, and having more than seven chambers in the last whorl. *M. occlusa* is distinguished from *M. velascoensis* and *M. acuta* by its narrower and shallower, open umbilicus.

***Geographical distribution and stratigraphical range:*** *Morozovella occlusa* was originally described by Loeblich and Tappan (1957) from the Palaeocene Velasco Formation of Mexico and was also reported by them from the Vincetown Formation of New Jersey, Salt Mountain Limestone of Alabama, and the Aquia Formation of Virginia. Bolli and Cita (1960b) described it as *M. acutispira* from the *G. pseudomenardii* to *G. velascoensis* Zones (Thanetian) of the Paderno d'Adda section of northern Italy. Hillebrandt (1962) recorded this species throughout the Lower, Middle and Upper Palaeocene of Austria. El-Naggar (1966) described *M. occlusa* from the *G. velascoensis* Zone of the Upper Palaeocene in the Esna-Idfu region of Egypt. Samanta (1970) recorded it from the Upper Palaeocene of the Pondicherry Formation of southern India. Samanta (1973) found *M. occlusa* in the *G. velascoensis* and *G. aequa* Zones in the Rakhi Nala section from Pakistan.

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella occlusa* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella acuta, M.* sp. cf. *parva* and *M. velascoensis* indicating a late Palaeocene age. However, this species occur within the *Morozovella velascoensis* Zone P5, which is equivalent to P5 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Morozovella* sp. cf. *G. parva***

Pl. 6, Figs.10-12, Pl. 7, Figs. 1-3

***Synonymy:*** *Globorotalia parva sensu* Luterbacher 1964, 678, tf. 91a-c. (not *G. velascoensis* (Cushman) var. *parva* Rey, 1955)

***Material:*** Four specimens from sample WM-22.

***Description:*** Test plano-convex with rugose surface. Periphery circular to slightly lobate with distinct keel. There are 4-5 subangular chambers which increase rapidly in size as the last whorl as added. Umbilical side strongly convex with well-developed umbilical shoulders, spiral side almost flat. Sutures on umbilical side depressed, radial; on spiral side curved, raised and beaded. Aperture a narrow, low arch. Umbilicus narrow and very deep.

***Dimensions:*** (in mm) The illustrated and figured specimen was measured (Pl. 6, Figs. 10-12 and Pl. and, Figs. 1-3).

| | |
|---|---|
| DIAMETER | 0.36 |
| HEIGHT | 0.23 |
| H/D | 0.64 |

***Remarks:*** The Oman material differs from the holotype of *Morozovella parva* Rey (1955) in being higher (0.27mm) or more conical in shape, in having more chambers in the last whorl and a more circular outline. *Morozovella parva* differs from *M. velascoensis* in the present material in having fewer chambers in the last whorl (four chambers), less lobate and a narrower, deeper umbilicus. The Oman specimen compares very well with the illustration and description of Luterbacher (1964) which argues that this "form" requires a name.

***Geographical distribution and stratigraphical range:*** *Morozovella parva* recorded from Morocco by Luterbacher (1964) from Palaeocene age.

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella* cf. *parva* was found in the Wadi Musawa section of the SE Oman mountains in association with *Morozovella velascoensis, M. acuta* and *M. angulata* indicating a late Palaeocene age. However, this species occur within *Morozovella velascoensis* Zone P5, which is equivalent to P5 of Blow (1969; 1979) and Berggren *et al.* (1988).

### *Morozovella pusilla mediterranica* (El-Naggar, 1966)

Pl. 7 Fig. 7-9

***Synonymy:*** *Globorotalia pusilla mediterranica* El-Naggar 1966, p.230-232, Pl. 19, Figs. 3a-c.

***Material:*** Three specimens in samples WM-1.

***Description:*** Test large (damaged), biconvex, tightly coiled in a low trochospiral. Periphery circular, moderately lobate and subacute. Test surface papillose. There are 5-6 crescentic, elongate chambers which increase moderately in size. Umbilical side strongly convex with high conical chambers and well-developed umbilical shoulders; spiral side moderately convex with elongate chambers. Umbilicus relatively wide, deep and open. Sutures on umbilical side straight, radial and strongly incised; on spiral side curved and depressed. Aperture a long arch with a narrow lip.

***Dimensions:*** (in mm) The described specimen was measured (Pl. 7, Figs. 7-9).

| | |
|---|---|
| DIAMETER | 0.41 |
| HEIGHT | 0.20 |
| H/D | 0.49 |

***Remarks:*** The Oman specimen compares very well with the specimen described and illustrated by El-Naggar (1966) from Egypt, but is larger in size (about 0.06 mm). *Morozovella pusilla mediterranica* differs from *M. pusilla pusilla* in that the former protrudes more on the umbilical side, has a distinct umbilical shoulder and a wider umbilicus.

***Geographical distribution and stratigraphical range:*** *Morozovella pusilla mediterranica* was originally described by El-Naggar (1966) from Egypt. He assigned it to the *G. pusilla* Subzone of the upper Middle Palaeocene, where he noted it ranges upwards into the overlying *G. pseudomenardi* Subzone, and dies out in the basal part of the Upper Palaeocene *G. aequa* / *G. esnaensis* Subzone.

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella pusilla mediterranica* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella acuta, M. angulata, M. nicoli* and *M. velascoensis* indicating a late Palaeocene age within *Morozovella acuta* Zone P4 local expression of the standard zone.

**_Morozovella subbotinae_ (Morozova, 1939)**

Pl. 8, Figs. 1-3

*Synonymy: Globorotalia subbotinae* Morozova 1939, p. 80, Pl. 2, Figs.16-17. - LUTERBACHER 1964, p. 676-679, text-Figs. 85-90. - STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 230, Fig. 89, nos. 3-4b. - TOUMARKINE and LUTERBACHER 1985, p. 112, Fig. 15, nos. 9-11.
*Morozovella subbotinae* (Morozova) BERGGREN, 1977, p. 239-241. - BERGGREN and NORRIS 1997, p. 94, 96, 98, 100, Pl. 16, Figs. 5, 9, 14, 21. *cum syn.*
*Globorotalia rex* Martin 1943, p. 117-118, Pl.8, Figs. 2a-c.

***Material:*** Seven specimens were picked from sample WME-98.

***Description:*** Test medium sized, low trochospiral. Periphery lobate, acute with thin spinose keel. Test surface covered by fine spines. There are 4-5 rhomboidal chambers which increase rapidly in size as added in the last whorl, with the last chamber occupying one quarter to one-fourth of the last whorl. Umbilical side strongly convex, spiral side almost flat, or slightly convex. Sutures on umbilical side depressed and radial; on spiral side curved, raised and beaded. Umbilicus narrow and deep. Aperture a low arch, extraumbilical-umbilical.

***Dimensions:*** (in mm) Three illustrated and figured specimens were measured (Pl. 8, Figs. 1-3).

| | Maximum | Minimum | Average |
|---|---|---|---|
| DIAMETER | 0.36 | 0.31 | 0.33 |
| HEIGHT | 0.19 | 0.17 | 0.18 |
| H/D | 0.53 | 0.55 | 0.54 |

***Remarks:*** The Oman specimens compare well with the specimens described and illustrated by Morozova (1939) and Luterbacher (1964). *Morozovella subbotinae* differs from *M. aequa* in having a distinct spinose keel and being less tightly coiled. *Morozovella subbotinae* also differs slightly from *G. rex* in having less compact chambers and a slightly lower umbilical side, but is still generally regarded as synonymous.

***Geographical distribution and stratigraphical range:*** *Morozovella subbotinae* was originally described by Morozova (1939) from the Lower Eocene of the Emba River of the USSR. Luterbacher (1964) recorded its range as from the base of his *G. aequa* Zone to the upper part of the *G. aragonensis* Zone, in the Gubbio section of central Italy. Samanta (1970) reported this species from the discocycliniid limestone and upper marlstone of the Palaeocene Pondicherry Formation of southern India. In Pakistan it ranges from the *G. aequa* Zone to the *G. formosa formosa* Zone (Samanta 1973). The overlap in range between *M. subbotinae* and *M. velascoensis* is a useful guide to the Palaeocene/Eocene boundary. Later, Stainforth *et al.*, (1975) and Toumarkine and Luterbacher (1985) reported that *M. subbotinae* ranges from the Late Palaeocene to the Early Eocene (within the *G. velascoensis* Zone to the *G. aragonensis* Zone) in the northern Caucasus (Shutskaya, 1956) and eastern Caucasus (Luterbacher, 1964).

***Local range and faunal associations:*** Previously unknown from Oman. *Morozovella subbotinae* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella aequa, M. caucasica* and *M. crater* indicating an early Eocene age. This species is found within *Acarinina pentacamerata* Zone P9, which is equivalent to P9 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Morozovella velascoensis*** **(Cushman, 1925)**

Pl. 8, Figs. 7-12

*Synonymy: Pulvinulina velascoensis* Cushman 1925a, p. 19, Pl. 3, Figs. 5a-c.
*Globorotalia velascoensis* Cushman BOLLI 1957a, p. 76, Pl. 20, Figs.1-4. - LOEBLICH and TAPPAN 1957, p. 196, Pl. 64, Figs. 1a-c, 2a-c. - LUTERBACHER 1964, p. 681-686, Figs. 92a-94c, 98a-99c. – POSTUMA 1971, p.218-219 STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 240-243, Fig. 97, nos. 1-5.
*Morozovella velascoensis* (Cushman) BERGGREN, 1977, p. 232-234. - BERGGREN andd NORRIS 1997, p. 72, 74, 76, Pl. 15, Figs. 10-14, 16-18, 22. *cum syn.*

***Material:*** Nineteen specimens in samples WM-7 and WM-22.

***Description:*** Test large, plano-convex with lobate and almost circular equatorial periphery, axial periphery acute with distinct peripheral keel. Test surface coarsely perforate and rugose. Five to eight angular chambers in the last whorl which increase slowly in size. Spiral side slightly raised with curved and raised sutures, umbilical side characterised by wide and deep, open umbilicus with well-developed shoulders. Aperture comprises a low arch borded by faint lip and is extraumbilical-umbilical.

***Dimensions:*** (in mm). Figured specimen was measured (Pl. 8, Figs. 7-12).

| | |
|---|---|
| DIAMETER | 0.46 |
| HEIGHT | 0.17 |
| H/D | 0.37 |

***Remarks:*** The most distinctive features of this species in the Oman material are the strongly convex umbilical side, with its wide, deep, open umbilicus and the distinct keel with its lobate periphery. Some specimens are identical to those described by Cushman (1925b: Pl. 3, Fig. 5). The Omani material shows a greater range of variation than previously recorded with some specimens being flatter and some approaching *M. acuta.* The number of chambers (5 to 8) and test diameter (0.40 to 0.46mm) vary markedly in the Oman material.

***Geographical distribution and stratigraphical range:*** *Morozovella velascoensis* is common in the Palaeocene and was originally described by Cushman (1925), from the Palaeocene Velasco Formation of Mexico. It ranges from the base of the *G. psuedomenardi* zone to the top of the *G. velascoensis* zone according to Hay (1960). *M. velascoensis* is recorded from numerous localities and has a wide geographic distribution from Trinidad to the Alpine-Mediterranean region and the Caucasus. *M. velascoensis* appears in Trinidad in the upper part of *G. pusilla pusilla* zone and ranges to the top of the *G. velascoensis* zone according to Bolli (1957). Bolli and Cita (1960a,b) found *M. velascoensis* range from the base of *G. pseudomenardii* zone to the top of the *G. velascoensis* zone in the Paderno d'Adda section of Italy. In the Gubbio section of Italy it ranges from the *G. psuedomenardii* zone of Bolli to the top of the *G. aequa* zone of Luterbacher. In southern India *M. velascoensis* occurs in the Pondicherry Formation, and ranges through the Late Palaeocene *Globorotalia psuedobulloides* and *Globorotalia velascoensis* Zones (Samanta, 1970). The species has also been recorded from the U. S. A. (Applin and Jordan, 1945); Pakistan (Haque, 1956); Mexico (Loeblich and Tappan, 1957); Morocco (Aubert, 1963); Iran (Kavary, 1963); Italy (Luterbacher, 1964); Egypt (EL-Naggar, 1966) and Jordan (Hamam and Haynes, 1977).

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella acuta, M. occlusa* and *M.* cf. *parva* indicating a late Palaeocene age. However, this species ranges from *Morozovella acuta* Zone P4 to *Morozovella velascoensis* Zone P5, which is equivalent to P4 to P5 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Morozovella* sp. A**

Pl. 9, Figs.1-3

***Material:*** Three specimens were picked from sample WME-94.

***Description:*** Test planispiral with flat spiral side and convex umbilical side. Periphery lobate with thin keel. There are 4-4.5 chambers which increase moderately in size as added in the last whorl. The chambers are semilunate on the spiral side and triangular to square on the umbilical side. The last chamber forms half of the final whorl. The umbilicus is open, deep and of intermediate width and has a umbilical shoulder on the last chamber. The sutures are straight and incised on the umbilical side and curved to raised on the spiral side. Aperture is a curved slit at the base of the last chamber and extends halfway towards the periphery. Test surface is covered by fine to coarse spines. The Omani material is characterised by the distinct shape of the test and chambers and the lobate test periphery.

***Dimensions:*** (in mm) Based on the figured specimen (Pl. 9, Fig. 1-3).

| | |
|---|---|
| DIAMETER | 0.42 |
| HEIGHT | 0.27 |
| H/D | 0.64 |

***Remarks:*** The Oman species is similar to *Globorotalia praenartanensis* Shutskaya (1956) which has a similar spiral side and chamber shape. However, *G. praenartansis* differs in having a very narrow umbilicus and smaller chambers in the last whorl whilst *Morozovella* sp. A has large, elongate chambers in the last whorl. The species is probably new but will await collection of additional material for description prior to formal naming.

***Geographical distribution and stratigraphical range:*** Previously unknown.

***Local range and faunal associations:*** Found in the Wadi Musawa section of the SE of Oman Mountains in association with *Morozovella formosa formosa, M. gracilis* and *A. pentacamerata* indicating an Early Eocene age within *Acarinina pentacamerata* Zone P8, and it is equivalent to P8 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

## *Morozovella* sp. B

Pl. 9, Figs. 4-6

***Material:*** Single specimen from sample WME-76.

***Description:*** Test oval with almost flat spiral side and convex umbilical side. Periphery subacute with a very thick and well-developed keel. Surface coarsely perforate. There are 4-5 chambers which increase slowly in size in the last whorl. Umbilicus is deep and narrow. Spiral sutures are thick and strongly curved, whilst umbilical sutures are incised and slightly curved. Aperture is a curved slit at the periphery with lip above it.

***Dimensions:*** (in mm) Based on the figured specimen (Pl. 9, Fig. 4-6).

| | |
|---|---|
| DIAMETER | 0.4 |
| HEIGHT | 0.2 |
| H/D | 0.5 |

***Remarks:*** The species appears to be new. However, since it is rare it will not be formally named until more material is available for study. Distinguished from other forms of the genus by its thick keel, thick peripheral margin and curved dorsal sutures (sutures about 0.03 mm thick).

***Geographical distribution and stratigraphical range:*** Previously unknown.

***Local range and faunal associations:*** Found in the Wadi Musawa section of the SE Oman Mountains. Rare occurrences within the marly shelly limestone of the Abat Formation associated with *Morozovella centralis, M.* sp. B, *Subbotina quadrata and Subbotina triangularis* indicating an early Eocene age within *Morozovella aragonensis* P8 and it is equivalent to P8 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Morozovella* sp. C**

Pl. 9, Figs. 7-12

***Material:*** Six specimens were examined from samples WME-98 and WME-103.

***Description:*** Test biconvex, low trochospiral with spiral side slightly convex, and umbilical side convex. Periphery acute to moderately lobate. There are 4-5 angular to subangular chambers which increase slowly in size as added in the final whorl. Umbilical sutures depressed and spiral sutures curved. The species is characterised by its biconvex test shape and spinose surface.

***Dimensions:*** (in mm) Two figured and illustrated specimens were measured (Pl.9, 7-12).

| | MAXIMUM | MINIMUM | AVERAGE |
|---|---|---|---|
| DIAMETER | 0.22 | 0.20 | 0.21 |
| HEIGHT | 0.13 | 0.11 | 0.12 |
| H/D | 0.59 | 0.55 | 0.57 |

***Remarks:*** The species is probably new being clearly distinguishable from all other forms of the genus by its test shape and ornamentation. Prior to formal naming additional material will be collected for further study. It is closest to *G. nicoli* Martin (1943: Pl. 7, Fig.3a-c), from which it is distinguished by its more convex test and well-rounded periphery.

***Geographical distribution and stratigraphical range:*** Previously unknown.

***Local range and faunal associations:*** Found in the marly limestone from the middle of the Wadi Musawa Section, SE Oman Mountains. It occurs in association with *Morozovella crater* indicating an early Eocene age within the *Acarinina pentacamerata* Zone P9, which is equivalent to P9 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

*Morozovella* **sp. D**

Pl. 10, Figs. 1-3

***Material:*** Two specimens were examined from sample WME-182.

***Description:*** Test compressed, low trochospiral with flat spiral side and convex umbilical side. Periphery rounded to subacute. Surface strongly perforated. There are five chambers which increase slowly in size as added in the last whorl. Shallow, open umbilicus. Sutures curved on spiral side and incised on umbilical side. Aperture comprises a low arch and is extra-umbilical to umbilical. The species is distinguished by its compressed test, perforated surface and curved sutures.

***Dimensions:*** (in mm) The described specimen (Pl. 10, Fig. 1-3) was measured.

| | |
|---|---|
| DIAMETER | 0.32 |
| HEIGHT | 0.15 |
| H/D | 0.47 |

***Remarks:*** Differs from all other known *Morozovella* species in having a depressed and flat test. Insufficient material currently available to justify formal naming as a new species.

***Geographical distribution and stratigraphical range:*** Previously unknown.

***Local range and faunal associations:*** Found in the Wadi Musawa section of the SE Oman Mountains in association with *Truncorotaloides topilensis* indicating a Middle Eocene age. This species is found in the middle part of *Truncorotaloides libyaensis* Zone P11 local zone of the standard zone.

| SPECIES | TEST |  | PERIPHERY | CHAMBERS |  | UMBILICAL SIDE | SPIRAL SIDE | UMBILICUS | SUTURES | APERTURE | DISTINGUISHING FEATURES | KEEL | AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | size | shape |  | number | shape |  |  |  |  |  |  |  |  |
| *Morozovella abundocamerata* | Medium | Trochospiral | Circular / Lobate | 6 to 7 | Angular | Convex | Flat | Narrow, deep and open | Radial - Curved | Low arch | Circular to rounded outline | Faint | Early Eocene |
| *Morozovella acuta* | Medium | Plano-convex | Acute / Rounded | 4 to 5 | Crescentic | Slightly convex | Flat | Wide and deep | Curved | Low arch | Ornament of bars on the umbilical shoulders | Narrow keel | Late Palaeocene |
| *Morozovella aequa* | Small | Low-trochospiral | Acute / Lobate | 4 to 4.5 | Angular | Convex | Flat | Narrow and deep | Radial-Depressed | Low arch | Last chamber elongate and occupies one third | Distinct and nodose keel | Early Eocene |
| *Morozovella angulata* | Medium | Low trochospiral | Subacute / Lobate | 5 to 7 | Angular/subangular | Strongly covex | Flat to slightly convex | Shallow, narrow and open | Radial - Curved | Low arch with faint lip | Faint lip, angular to conical chambers in the last whorl | Faint keel | Late Palaeocene |
| *Morozovella aragonensis* | Medium | Umbilico-convex | Rounded / Acute | 5 to 6 | Angular | Strongly covex / Conic | Flat | Narrow and deep | Radial,Curved slightly raised | Low arch with faint lip | Circular to rounded outline with thick rugose wall | Ornament keel | Early Eocene |
| *Morozovella bolivariana* | Large | Umbilico-convex | Broadly rounded | 4 to 4.5 | Subglobular | Convex | Flat, raised at inner portion | Narrow and open | Radial, depressed and curved | Narrow boarded by a lip | Large test, broadly rounded and slightly lobate periphery | Absent | Middle to Late Eocene |
| *Morozovella caucasica* | Medium | Umbilico-convex | Rounded / Acute | 6 to 8 | Conical | Strongly convex | Flat | Deep and wide | Radial, depressed and raised | Low arch with distinct lip | Coarse ornamentation and crown-shape in peripheral view | Distinct keel | Early Eocene |
| *Morozovella centralis* | Medium | Umbilico-convex | Rounded, subangular | 4 | Inflated | Distinctly convex | Flat to slightly convex | Narrow | Depressed and strongly oblique | Large arch, elongate | Rounded to circular periphery and large arch aperture | Absent | Early Eocene |
| *Morozovella crater* | Medium | Umbilico-convex | Subangular | 5 | Angular | Strongly convex | Flat to slightly convex | Narrow and deep | Radial, curved and beaded | Low arch | Subangular with well-developed keel and small spinose projection | Well developed keel | Early Eocene |
| *Morozovella edgari* | Small | Umbilico-convex | Lobate / Acute | 4.5 to 6 | Triangular | Strongly convex | Flat to slightly convex at inner portion | Narrow and deep | Depressed , straight and flush | Low arch with imperforate lip | Kummerform last chamber and flush spiral side sutures | Well developed keel | Middle Eocene |
| *Morozovella formosa formosa* | Medium | Umbilico-convex | Lobate | 5 to 6 | Angular | Strongly convex | Flat spinose | Wide, deep and open | Radial and curved | Low arch | Faint and spiny keel. | Spiny | Early Eocene |
| *Morozovella gracilis* | Small | Umbilico-convex | Acute to slightly lobate | 6 to 7 | Angular | Strongly convex | Flat to slightly convex at inner portion | Deep and narrow | Flush and depressed | Low arch with narrow lip | Spinose keel, flush sutures and low arch aperture with narrow lip | Spinose | Early Eocene |
| *Morozovella marginodentata* | Large | Biconvex | Lobate | 5 to 6 | Subangular | Convex | Slightly convex | Narrow and deep | Curved and depressed | Low arch with thick lip | Rounded shape and low arch aperture with thick lip | Thick keel | Early Eocene |
| *Morozovella nicoli* | Small | Biconvex | Acute | 5 to 5.5 | Subangular | Convex | Flat | Narrow and open | Curved | Low arch | Biconvex shape and narrow umbilicus | Narrow keel | Late Eocene |
| *Morozovella occlusa* | Medium | Biconvex | Subcircular | 5 to 7 | Subangular | Convex | Slightly convex | Narrow and shallow | Radial and raised | Low arch | Subcircular periphery and coarse ornamentation | Spinose keel | Late Palaeocene |
| *Morozovella cf M perva* | M-Large | Plano-convex | Circular / Lobate | 4 to 5 | Subangular | Convex | Flat | Narrow and very deep | Radial depressed | Narrow with low arch | Plano-convex, Rugose surface, cicular periphery and narrow aperture | Distinct keel | Late Palaeocene |
| *M. pusilla mediterranica* | Large | Biconvex | Circular and lobate | 5 to 6 | Crescentic/elongate | Convex | Moderately convex | Wide, deep and open | Straight, radial and incised | Long arch with narrow lip | Crescentic chambers and long arch aperture with narrow lip | Absent | Early Eocene |
| *Morozovella subbotinae* | Medium | Umbilico-convex | Lobate, acute | 4 to 5 | Rhomboidal | Convex | Flat | Deep and narrow | Radial, raised and beaded | Low arch | Spinose keel and rhomboidal chambers in the last whorl | Spinose | Late Eocene |
| *Morozovella velascoensis* | Large | Plano-convex | Circular | 5 to 6 | Angular | Convex | Flat to raised | Wide and deep | Raised | Low arch | Plano-convex and circular periphery with distinct peripheral keel | Distinct keel | Late Palaeocene |
| *Morozovella sp A* | Medium | Planospiral | Lobate | 4 to 4.5 | Semilunate | Convex | Flat | Deep and open | Straight, curved and incised | Curved slit | Planispiral test and semilunate to square chambers | Thin keel | Early Eocene |
| *Morozovella sp B* | Medium | Oval | Subacute | 4 to 5 |  | Convex | Flat | Deep and narrow | Curved and thick | Curved slit with lip above it | Oval shape, peripheral margin and thick curved sutures | Thick keel | Early Eocene |
| *Morozovella sp C* | Small | Biconvex | Rounded and lobate | 4 to 5 | Angular to subangular | Convex | Slightly convex | Narrow | Depressed and curved | Thin and low arch | Biconvex shape and spinose surface | Thin keel | Early Eocene |
| *Morozovella sp D* | Small | Compressed | Rounded | 5 | Subangular | Convex | Flat | Shallow and open | Curved and incised | Low arch | Compressed test, perforate surface and curved sutures | Absent | M-Late Eocene |

Fig. 4.2 Summary of key morphological features of studied planktonic foraminifera (*Morozovella*).

**Genus *Acarinina* Subbotina ,1953**

Test strongly inflate d, chambers of the *Globigerina* type; spiral side slightly flattened; umbilical side strongly convex; umbilicus small, barely discernible or large and very distinct. Periphery frequently rounded without keel. Chambers are loosely arranged in most species. Aperture slit-like, along the marginal suture, often without a lip. Coarse spinose wall; particularly near the umbilicus. Age range from Middle Palaeocene (basal Thanetian), from near base of *Planorotalites pusilla pusilla* Zone (P3) to Upper Middle Eocene (uppermost Bartonian) upper part of *Truncorotaloides rohri* Zone (P14) of Blow (1969) and Berggren and Van Couvering (1974)

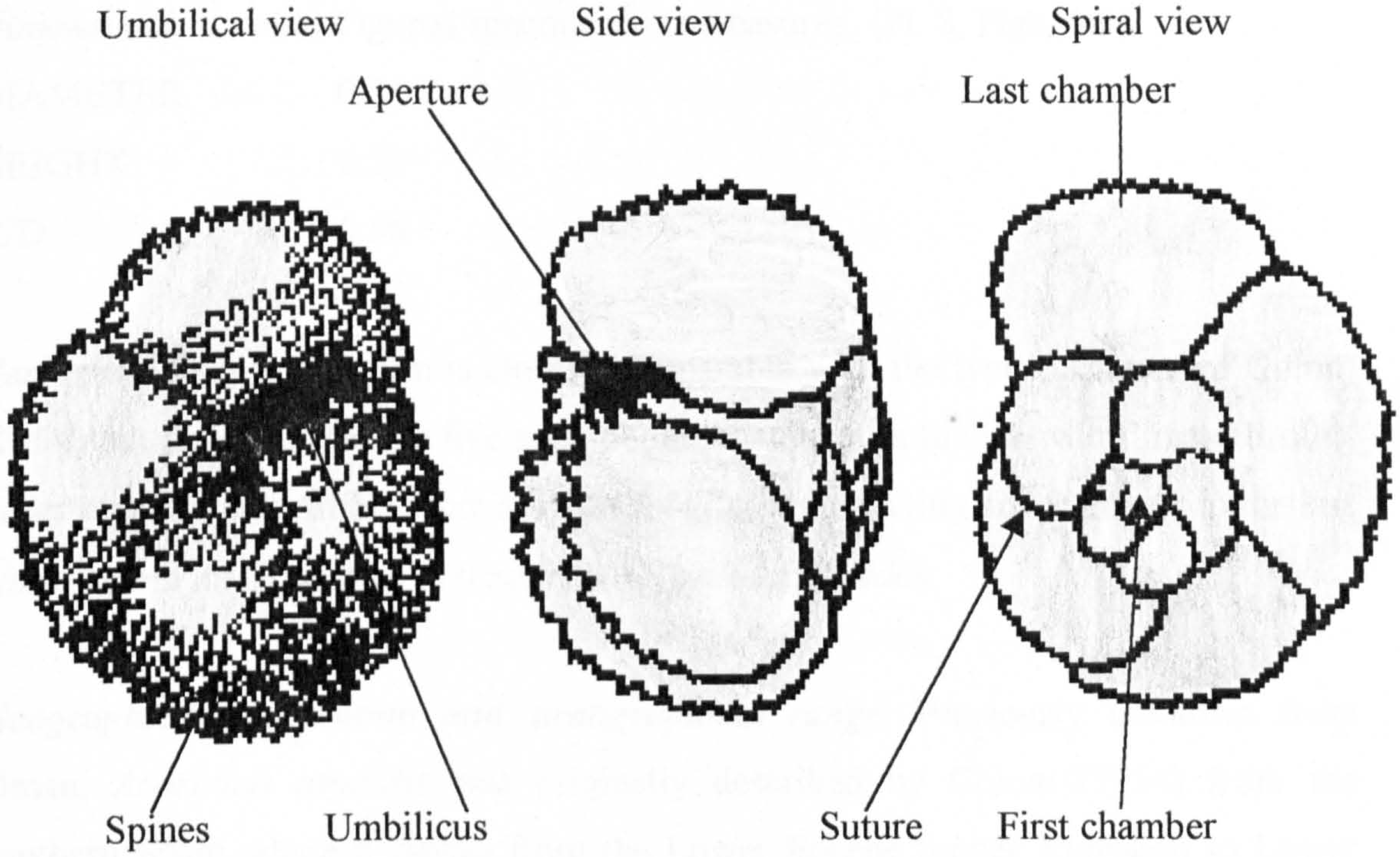



**Fig. 4.3 Morphology of *Acarinina* (after Banner, 1982).**

TYPE SPECIES: *Acarinina acarinata* Subbotina 1953

***Acarinina aspensis*** (Colom) 1954

Pl. 8, Figs. 4-6

***Synonymy:*** *Globigerina aspensis* Colom 1954, p. 151-154, Pl. 3, Figs. 1-35, Pl. 4, Figs. 1-31.

*Acarinina aspensis* (Colom) BERGGREN , 1977, p. 258-259.

***Material:*** One specimen in sample WM-35.

***Description:*** Test medium sized, very low trochospiral. Periphery circular, slightly lobate and broadly rounded. Test surface rugose and finely perforate. There are 5 subglobular chambers which increase slowly in size in the last whorl as each chamber is added. Umbilical side inflate d, spiral side depressed. Sutures on umbilical side radial, depressed; on spiral side sutures are deep, radial and slightly curved. Aperture a low arch, extraumbilical-umbilical borded with faint lip. Umbilicus deep, wide and open.

***Dimensions:*** (in mm) Figured specimen was measured. (Pl. 8, Figs. 4-6)

| | |
|---|---|
| DIAMETER | 0.34 |
| HEIGHT | 0.19 |
| H/D | 0.56 |

***Remarks:*** The present form is closely comparable with the type specimen of Colom (1954) but differs in having five subglobular chambers in the last whorl instead of 6. *Acarinina aspensis* differs from *M. psuedobulloides* in having six chambers in the last whorl and in its larger size to 0.5mm in *M. psuedobulloides.*

***Geographical distribution and stratigraphical range*:** Previously unknown from Oman. *Acarinina aspensis* was originally described by Colom (1954) from the southern Spain where it ranges from the Lower Eocene (upper Ypresian) to Lower Lutetian. Bolli (1957a) recorded from *Acarinina densa* Zone to *Globigerinapsis kigleri* Zone.

***Local range and faunal associations:*** Previously unknown from Oman. *Acarinina aspensis* is found in Wadi Musawa section SE of Oman Mountains. It occurs in association with *Acarinina esnaensis* and *Acarinina soldadoensis* indicating an early Eocene age within*Acarinina pentacamerata* P8, which equivalent to P8 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Acarinina esnaensis* (Le Roy, 1953)**

Pl. 10, Figs. 4-9

***Synonymy:*** *Globigerina esnaensis* Le Roy 1953, p. 31, Pl. 6, Figs. 8-10. - NAKKADY 1959, p. 461, Pl. 3, Figs. 2a-c. - GARTNER and HAY 1962, p. 563, Pl. 2, Figs. 4a-c. - SAID and SABRY 1964, p. 383, Pl. 1, Fig. 5. - JENKINS 1971, p. 82, Pl. 3, Figs. 84 -88. - SAMANTA 1973, p. 457, Pl. 15, Figs. 7-9.
*Acarinina esnaensis* (Le Roy) BERGGREN, 1977, p. 249, 250

***Material:*** Four specimens in sample WM-35.

***Description:*** Test small and oval in shape. Periphery subquadrate, lobate with fine spines. Four subspherical chambers in the last whorl increasing very slowly in size (almost equal). Spiral side almost flat with depressed sutures and covered with variable ornamentation from fine spines on the early chambers to strong pores towards the edges. Umbilical side ornamented with well-developed coarse spines, and narrow, shallow umbilicus with incised sutures. Aperture positioned at the umbilical depression with slight lip.

***Dimensions:*** (in mm) Two described and illustrated specimens were measured (Pl. 10, Figs. 4-9).

| | MAXIMUM | MINIMUM | AVERAGE |
|---|---|---|---|
| DIAMETER | 0.38 | 0.30 | 0.33 |
| HEIGHT | 0.21 | 0.18 | 0.19 |
| H/D | 0.55 | 0.60 | 0.57 |

***Remarks:*** In Le Roy (1953) the spiral side is described as inflate d, however, in the Oman material it is slightly flat but still displays all the other characteristics of the species mentioned by Le Roy. Jenkins (1971) stated that *Acarinina esnaensis* was distinguished by its distinctive rimmed aperture which extends from the umbilicus to the periphery a feature which is clearly seen in the Oman material. *Acarinina esnaensis* differs from *Acarinina acarinata* and *A. aquiensis* in that the latter both have a tight, open umbilicus and are smaller in size.

***Geographical distribution and stratigraphical range:*** *Acarinina esnaensis* was originally described from the basal part of the Esna Shale of Egypt which was assigned by Le Roy to the Lower Eocene. Said and Kerdany (1961) later regarded *Acarinina esnaensis* from the same area as late Palaeocene in age. Loeblich and Tappan (1957) reported *A. esnaensis* from the Upper Palaeocene of the Gulf and Atlantic Coastal Plains of the United States whilst Gartner and Hay (1962) reported it from the Ilerdian of Spain and France. El-Naggar (1966) reported *A. esnaensis* from the Egyptian Esna Shale and assigned it to *Globorotalia aequa* Zone and *Globorotalia esnaensis* subzone i.e. Upper Palaeocene/Lower Eocene. Samanta (1970) found *A. esnaensis* in the Upper Palaeocene Pondicherry Formation of southern India and assigned it to the *G. pseudomenardii* and *G. velascoensis* zones.

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Acarinina soldadoensis*, *Operculina* cf *aspensis*, *Neorotalia* and *Lenticulina* indicating an early Eocene age within *Morozovella aragonensis* Zone P8, which equivalent of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Acarinina pentacamerata* (Subbotina, 1947)**

Pl. 7, Figs. 4-6

***Synonymy:*** *Globorotalia pentacamerata* Subbotina 1947, p. 128, Pl. 7, Figs. 12-17; Pl. 9, Figs. 26-29. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 212-213, Figs. 73, nos. 1a-2c. – BLOW 1979, p. 939-941, Pl. 135, Figs. 5.

*Acarinina pentacamerata* (Subbotina) BERGGREN, 1977, p. 254-257. *cum syn.*

*Globorotalia aspensis* (Colom). POSTUMA 1971, p. 174-175.

***Material:*** Two specimens in sample WME-94. (Both damaged)

***Description:*** Test small, low trochospiral. Periphery almost rounded, no keel developed. Test surface strongly perforate on spiral side; finely perforate on umbilical side with well-developed pustules on umbilical shoulders. There are 5-6 elongate chambers in spiral view, which increase moderately in size in the last whorl. Umbilical side inflate d, spiral side slightly flattened. Sutures radial on umbilical side; on spiral side curved and depressed. Umbilicus moderately wide and deep. Aperture a low arch, extraumbilical-umbilical.

***Dimensions:*** (in mm). The described and illustrated specimen was measured (Pl. 7, Figs. 4-6).

| | |
|---|---|
| DIAMETER | 0.29 |
| HEIGHT | 0.18 |
| H/D | 0.62 |

***Remarks:*** The Oman specimens compare well with the specimen described by Subbotina (1953) but this is slightly different from the type which was described previously by Subbotina (1947). Toumarkine and Luterbacher (1985) consider *Globorotalia (A.) aspensis* Colom (1954) and *Globorotalia pentacamerata* Subbotina (1947) to be closely interrelate d by transitional forms (e.g. Stainforth *et al.*, 1975) whilst Hillebrandt (1976) and Blow (1979) keep them as separate species.

***Geographical distribution and stratigraphical range:*** ***Acarinina pentacamerata*** was riginally described by Subbotina (1947; 1953) from the Lower Eocene of the northern Caucasus, Soviet Union.

***Local range and faunal associations:*** Previously unknown from Oman. *Acarinina pentacamerata* was found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella marginodentata, Morozovella aragonensis* and *Morozovella caucasica* indicating an early Eocene age within *Acarinina pentacamerata* P9, which is equivalent to P9 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively

***Acarinina soldadoensis* (Bronnimann, 1952)**

Pl. 10, Figs.10-12, Pl. 11, Figs. 1-3

*Synonymy: Globigerina soldadoensis* Bronnimann 1952, p. 7,9, Pl. 1, Figs. 1-9. - SAMANTA 1970c, p. 612, Pl. 95, Figs. 14-15. – POSTUMA 1971, p. 158-159. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 229, Fig. 87, nos. 1-3, 5.

*Acarinina soldadoensis* (Bronnimann) BERGGREN, 1977, p. 257, 258. - BERGGREN and NORRIS 997, p. 68, Pl. 11, Figs. 6, 8-15, 21. *cum syn.*

*Material:* Eighteen specimens in sample WM-35.

*Description:* Test compact with five chambers which double in size in the last whorl. Tightly coiled with a flattened spiral side and inflate d umbilical side. Well-developed spines occur over the entire test surface. Sutures are incised and curved on the spiral side and radial on the umbilical side. Tightness of coiling and occurrence of fine to coarse spines vary between specimens. The shape of the periphery; size and shape of the chambers in the last whorl and the test ornamentation (fine to coarse spines) are the main features which vary within the material studied.

*Dimensions:* (in mm) Two figured and illustrated specimens were measured from sample WM-35 (Pl. 10, Figs. 10-12 and Pl. 11, Figs. 1-3).

| | MAXIMUM | MINIMUM | AVERAGE |
|---|---|---|---|
| DIAMETER | 0.35 | 0.33 | 0.34 |
| HEIGHT | 0.20 | 0.18 | 0.19 |
| H/D | 0.57 | 0.54 | 0.56 |

*Remarks:* The present specimens agree closely with the original description of *Globigerina soldadoensis* of Bronnimann (1952). Chambers in the last whorl tend to be elongated in the direction of coiling towards the last chamber in the last whorl. The last chamber shows only a slight increase in size over the previous one in dorsal view. *Acarinina soldadoensis* is closely relate d to *Globigerina mckannai* White (1928: Pl. 27, Fig. 16a-c) from which it is distinguished by its flatter dorsal side, fewer, less globular chambers in the last whorl and more lobate periphery. Previous workers (e.g. Bronnimann, 1952) have suggested that *A. soldadoensis* evolved from *A. mckannai.*

***Geographical distribution and stratigraphical range:*** *Acarinina soldadoensis* was originally described from the Palaeocene-Lower Eocene of Trinidad by Bronnimann (1952) and is known to occur throughout the Palaeocene Pondicherry Formation of Southern India (Samanta, 1973).

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Acarinina esnaensis,* indicating an Early Eocene age within *Morozovella aragonensis* Zone P8, which equivalent of P8 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Acarinina* sp.**

Pl. 11, Figs. 4-6

***Material:*** Two poorly preserved specimens from sample WM-35.

***Description:*** Test compact, with smooth surface and rounded to subacute periphery. Spiral side flat to slightly concave at the centre with straight to slightly depressed sutures. There are 4-4.5 subglobular chambers in the last whorl, with a marked increase in size compared with the much smaller chambers of the earlier whorls. Wall strongly perforated. Umbilical sutures are deep and curved with globular chambers in the early stage of the last whorl. Deep, wide, open umbilicus with a low, arched aperture open to the umbilicus. The compact test, strongly perforated test wall and deep umbilicus are characteristic of this species.

***Dimensions:*** (in mm) Based on figured specimen (Pl. 11, Fig. 4-6).

| | |
|---|---|
| DIAMETER | 0.30 |
| HEIGHT | 0.10 |
| H/D | 0.33 |

***Remarks:*** This species has an open umbilicus similar to *A. soldadoensis*, but differs in having a smooth perforated test whilst in *A. soldadoensis* the test is coarsely spinose.

***Geographical distribution and stratigraphical range:*** Previously unknown from Oman.

***Local range and faunal associations:*** Found in the Wadi Musawa section of the SE Oman Mountains in association with *Acarinina soldadoensis* and *A. esnaensis* indicating an Early Eocene age within *Morozovella aragonensis* Zone P8, which equivalent of P6 of Blow (1969; 1979) and Berggren *et al.* (1988).

| SPECIES | TEST | | PERIPHERY | CHAMBERS | | UMBILICAL SIDE | SPIRAL SIDE | UMBILICUS | SUTURES | APERTURE | DISTINGUISHING FEATURES | AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | size | shape | | number | shape | | | | | | | |
| *Acarinina aspensis* | Medium | Depressed | Circular | 5 to 6 | Subglobular | Inflated | Depressed | Wide and open | Radial and curved | Low arch borded by faint lip | Depressed and inflated test with low arch aperture | Early Eocene |
| *Acarinina esnaensis* | Small | Oval | Subquadrate | 4 | Subspheical | Slightly convex | Flat | Narrow and shallow | Incised and depressed | Positioned at the umbilical depressio | Oval shape, subquadrate periphery and subspherical chambers | Early Eocene |
| *Acarinina pentacamerata* | Small | Biconvex | Rounded | 5 to 6 | Elongate | Inflated | Flattened | Moderately wide and deep | Radial depressed | Low arch | Rounded periphery and elongate chambers in the final whorl | Early Eocene |
| *Acarinina soldadoensis* | Medium | Compact | Lobate | 5 | Elongate | Inflated | Flattened | Narrow, shallow and open | Incised and radial | Umbilico | Compact shape, tightness of coiling and occurrence of spines | Early Eocene |
| *Acarinina sp.* | Small | Compact | Subrounded | 4 to 4.5 | Subglobular | Inflated | Flat to slightly c | Deep, wide and open | Straight, depressed and deep | Low arch | Compact test, strongly perforated wall and deep umbilicus | Early Eocene |

**Fig. 4.4 Summary of key morphological features of studied planktonic foraminifera (*Acarinina*).**

**FAMILY GLOBIGERINIDAE Carpenter , Parker and Jones, 1862**

**Genus *Subbotina* Brotzen andPozaryska 1961**

Test free, trochospiral, chambers spherical to ovate; wall calcareous, perforate, radial in structure, surface may be smooth, pitted cancellate d, hispid or spinose; aperture interiomarginal, umbilical, with tendency in some species to extend to slightly extraumbilical position, previous apertures remaining open into umbilicus. Age range from Early Palaeocene, base of *Globigerina eugubina* Zone (P1a) of Berggren and Van Couvering (1974) to Recent.

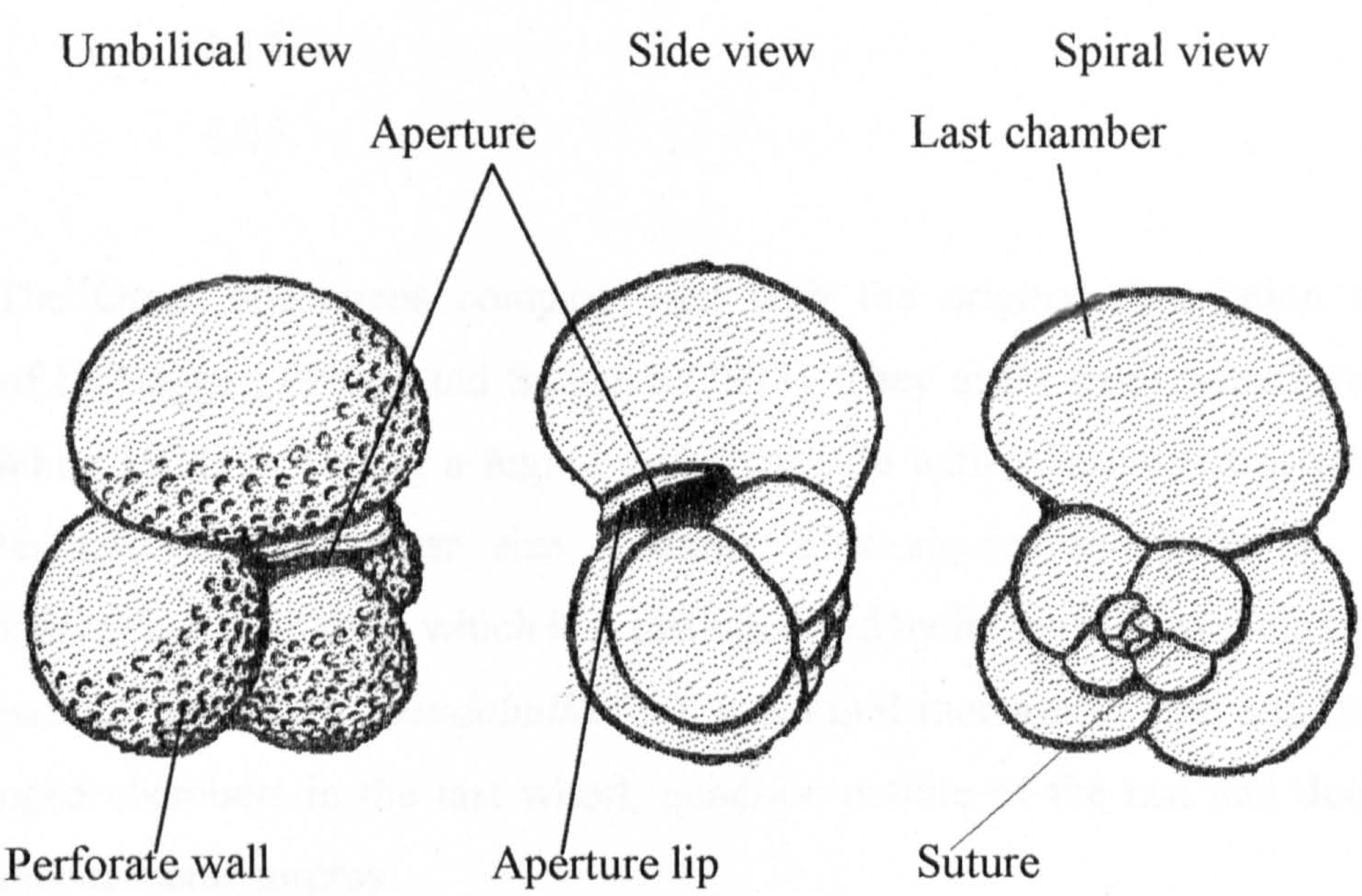



**Fig. 4.5 Morphology of *Subbotina* (modified from Banner, 1982).**

TYPE SPECIES *Globigerina triloculinoides* Plummer, 1926

***Subbotina quadrata* (*sensu* El-Naggar, 1966)**

Pl. 7, Figs.10-12

***Synonymy:*** *Globorotalia quadrata sensu* El-Naggar 1966, p. 233-234, Pl. 18, Figs. 4a-c. - SAMANTA 1973, p.462-463, Pl. 12, Figs. 4-6. (Not *Globigerina quadrata* White 1928).

***Material:*** Two specimens in sample WME-76.

***Description:*** Test medium sized, inflate d, coiled in a low trochospiral with initial whorl projecting. Periphery quadrate. distinctly lobate and rounded. Test surface finely perforated, smooth towards the last chamber. There are 4 globular chambers which increase rapidly in size in the last whorl as added. Sutures on the umbilical side are radial and strongly entrenched; on the spiral side sutures are curved in the early coil, straight, radial and depressed in the final whorl. Umbilicus wide, deep and open.

***Dimensions:*** (in mm) The figured and illustrated specimen was measured (Pl. 7, Figs. 10-12).

| | |
|---|---|
| DIAMETER | 0.20 |
| HEIGHT | 0.13 |
| H/D | 0.65 |

***Remarks:*** The Oman specimens compare well with the original description and illustration of El-Naggar, (1966) and Samanta (1973). They differ from *Morozovella quadrata* (White 1928) in having a higher umbilical side with a raised initial whorl and, a faster rate of a chamber size increase. This species is similar to *M. pseudobulloides* (Plummer) from which it is distinguished by its fewer chambers (four in *M. quadrata* to five in *M. pseudobulloides*), less rapid increase in size and more tightly arranged chambers in the last whorl, quadrate outline of the test and deeply excavated inter-cameral sutures.

***Geographical distribution and stratigraphical range:*** This form was originally described by El-Naggar (1966) and reported as *M. 'quadrata'* from the Upper Danian to the lower part of the Upper Palaeocene in the Esna-Idfu region of Egypt. Samanta (1970) recorded *M. 'quadrata'* from the Palaeocene Pondicherry formation of the southern India and late r (Samanta, 1973) found *M. 'quadrata'* in the Rakhi Nala section of Pakistan, throughout the *G. formosa formosa* and *Globorotalia aspensis/Globorotalia esnaensis* Zones.

***Local range and faunal associations:*** Previously unknown from Oman. *Subbotina quadrata* was found in the Wadi Musawa section of the SE Oman Mountains where it occurs in association with *Morozovella caucasica Morozovella centralis, Subbotina* *quadrata* and *Subbotina triangularis* indicating an Early Eocene age within Zone P8 which is equivalent to P8 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Subbotina triangularis*** **(White, 1928)**

Pl. 11, Figs. 7-9

***Synonymy:*** *Globigerina triangularis* White 1928, p. 195-196, Pl. 28, Figs. 1a-b. - BOLLI 1957, p. 71, Pl. 15, Figs. 12-14. - PROTO DECIMA and ZORZI 1965 p. 17-18, Pl. 1, Figs. 4a-c. SAMANTA 1973, p. 443-444, Pl. 2, Figs. 13-15.
*Subbotina triangularis* (White) BERGGREN and NORRIS 1997, p. 43-44, Pl. 5, Figs. 1, 5, 9. *cum syn.*

***Material:*** Two specimens in sample WME-76.

***Description:*** Test triangular, low trochospiral. Periphery rounded lobate. Test surface strongly perforated and reticulate. There are 4 spherical to ovate chambers which increase rapidly in size as added in the last whorl. Umbilicus small and shallow. Sutures on umbilical side radial; on spiral side depressed, slightly curved. Aperture umbilical, low arch.

***Dimensions:*** (in mm). The figured specimen was measured (Pl. 11, Figs.7-9).

| | |
|---|---|
| DIAMETER | 0.31 |
| HEIGHT | 0.19 |
| H/D | 0.61 |

***Remarks:*** The Oman specimen compares well with the specimen described and illustrated by Samanta (1973). It differs slightly from the type of White (1928) in having four instead of three chambers in the last whorl. *Subbotina triangularis* differs from *Subbotina triloculinoides* in having 4 spherical chambers and a small shallow umbilicus.

***Geographical distribution and stratigraphical range:*** *Subbotina triangularis* was originally described by White (1928) from the base of the Upper Cretaceous lower Velasco formation, of Mexico. Bolli (1957) recorded it from Palaeocene/Lower Eocene of Trinidad and stated it ranged from the *Globorotalia pusilla pusilla* Zone to the Lower Eocene, *Globorotalia aragonensis* Zone. According to Samanta (1973) the range of *Subbotina triangularis* in the Rakhi Nala section of Pakistan is from the *Globorotalia velascoensis* Zone to the *Globorotalia formosa formosa* Zone.

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section in association with *Morozovella caucasica* indicating an Early Eocene age within *Morozovella aragonensis* Zone P8 which is equivalent to Zone P8 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Subbotina triloculinoides*** **(Plummer, 1926)**

Pl. 11, Figs. 10-12

***Synonymy:*** *Globigerina triloculinoides* Plummer 1926, p.134, Pl. 8, Figs. 10a-b. - BOLLI 1957, p. 70, Pl. 15, Figs.18-20. - BERGGREN 1962, p. 86, Pl. 14, Figs.1a-2b. - SAMANTA 1970, p. 614, Pl. 94, Figs. 5,9,13-16. – POSTUMA 1971, p. 160-161. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 234, Fig.92, nos. 1-4.

*Subbotina triloculinoides* (Plummer) BERGGREN and NORRIS 1997, p. 42-43, Pl. 4, Figs. 1-3, 5-7, 9-10, 19, 21, 22. *cum syn.*

***Material:*** Ten out of fifteen specimens from sample WM-7 were well enough preserved and these form the basis of the description.

***Description:*** Test tightly coiled, low trochoid, with globose chambers and a rounded and distinctly lobate periphery. Test surface has a distinctive honeycomb pattern. There are 3 globular chambers in the last whorl which rapidly increase in size so that the last chamber occupies about one half of the test. Spiral side slightly raised and umbilical side inflate d with very narrow open umbilicus. Sutures are depressed to slightly curved on spiral side, incised and radial on umbilical side. Low aperture beneath narrow lip.

***Dimensions:*** (in mm) Figured specimen was measured (Pl. 11, Fig. 10-12).

| | |
|---|---|
| DIAMETER | 0.35 |
| HEIGHT | 0.24 |
| H/D | 0.68 |

***Remarks:*** The specimens agree closely with the original description and figures of *Subbotina triloculinoides* Plummer (1926). However, the type is smaller in size (0.26 mm) and has a larger chamber in the last whorl. The main variation in the Oman material is in the size of the test, which is generally larger than previously recorded for *Subbotina triloculinoides* populations.

***Geographical distribution and stratigraphical range:*** *Subbotina triloculinoides* was originally described from the Palaeocene (*Globorotalia pseudobulloides* Zone to *Globorotalia pseudomenardii* Zone), of the Midway Formation, Texas by Plummer (1926). Haynes (1956) reported it from the Thanetian of England whilst Troelsen (1957) recorded it from the Upper Danian of Denmark. Bolli (1957) reported it from the lower part of the Palaeocene Lower Lizard Spring Formation of Trinidad. Hay (1960) recorded it from the Palaeocene Velasco Formation of Mexico and it is also known from the Palaeocene Gebel Owaina section of Egypt (El-Naggar, 1966). *Subbotina triloculinoides* occurs in southern India (Samanta, 1970) and Pakistan (Samanta, 1973).

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella acuta* and *Morozovella angulata* indicating a Late Palaeocene age within *Morozovella acuta* P4 of local expression of the standard zones, Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

| SPECIES | TEST | | PERIPHERY | CHAMBERS | | UMBILICUS | SUTURES | APERTURE | DISTINGUISHING FEATURES | AGE |
|---|---|---|---|---|---|---|---|---|---|---|
| | size | shape | | number | shape | | | | | |
| *Subbotina quadrata* | Medium | Inflated | Quadrate, lobate | 4 to 5 | Globular | Deep, wide and open | Radial and straight | Absent | Quadrate periphery and globular chambers | Early Eocene |
| *Subbotina triangularis* | Medium | Triangular | Rounded/Lobate | 4 | Spherical | Small and shallow | Radial to curved | Umbilical low arch | Triangular shape, rounded periphery and strong reticulate surface | Early Eocene |
| *Subbotina triloculinoides* | Medium | Rectangular | Rounded/Lobate | 3 | Globular | Narrow | Curved, incised and radial | Low arch beneath narrow lip | Rectangular shape, surface honeycomb pattern and narrow umbilicus | Late Palaeocene |

**Fig. 4.6 Summary of key morphological features of studied planktonic foraminifera (*Subbotina*).**

**Genus *Truncorotaloides* Bronnimann and Bermudez, 1953**

Test low trochoidal planoconvex with a spire of two whorls. Final whorl contains 5-6 subangular chambers, spiral side slightly convex to almost flat, umbilical side strongly convex. Sutures straight to curved. Umbilicus deep and small. Aperture large arcuate, with lip-like borders. Surface with heavy spines. Wall finely perforate. Age range from Early Eocene (uppermost Ypresian), from *Acarinina pentacamerata* Zone (P9) to Middle Eocene (uppermost Bartonian), top of *Truncorotaloides rohri* Zone (P14) according to Blow (1969) Berggren and Van Couvering, (1974).

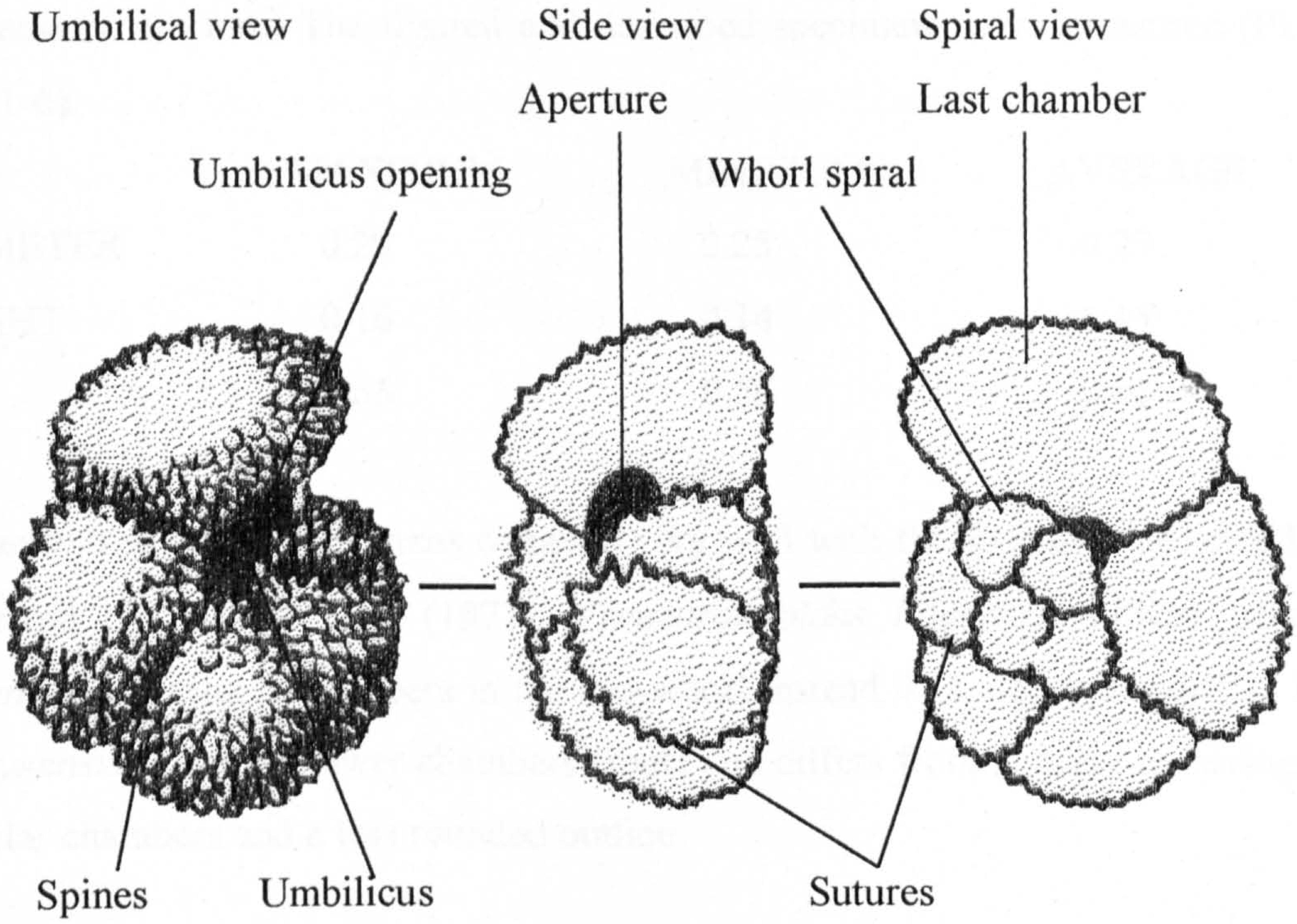



**Fig. 4.7 Morphology of *Truncorotoloides* (modified from Banner, 1982).**

TYPE SPECIES *Truncorotaloides rohri* Bronnimann and Bermudez, 1953

***Truncorotaloides libyaensis* (El-Khoudary, 1977)**

Pl. 12, Figs. 1-6

***Synonymy:*** *Truncorotaloides libyaensis* El-Khoudary 1977, p. 330-331, Pl. 2, Figs. 1-23.

***Material:*** Five specimens in sample WME-186 and WME-205.

***Description:*** Test medium sized, subrectangular. Periphery rectangular to subrectangular, slightly lobate. Test distinctly perforate, rugose surface. There are 5 subangular chambers which increase rapidly in size in the last whorl as added. Umbilical side strongly convex with subglobular chambers, spiral side almost flat to slightly convex with flat, elongate rectangular chambers. Sutures on umbilical side radial; on spiral side depressed and slightly curved to straight. Umbilicus deep and wide. Aperture a low arch, extraumbilical-umbilical with liplike border.

***Dimensions:*** (in mm) The figured and described specimens were measured (Pl. 12, Figs. 1-6).

| | MAXIMUM | MINIMUM | AVERAGE |
|---|---|---|---|
| DIAMETER | 0.29 | 0.25 | 0.27 |
| HEIGHT | 0.16 | 0.14 | 0.15 |
| H/D | 0.55 | 0.56 | 0.55 |

***Remarks:*** The Oman specimens compare very well with the specimen described and illustrated by El-Khoudary (1977). *Truncorotaloides libyaensis* differs from *T. topilensis* in having 5 chambers in the last whorl instead 4. *T. libyaensis* differs from *T. haynensis* in having fewer chambers (four) and differs from *T. rohri* in having less globular chambers and a less rounded outline.

***Geographical distribution and stratigraphical range:*** *Truncorotaloides libyaensis* was originally described by El-Khoudary (1977) from the Middle Eocene, Apollonia Formation of the northern Jabal Al Akhdar, Libya.

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella bolivariana* and *Globigerinatheka curryi* indicating a Middle Eocene age within *Truncorotaloides libyaensis* Zone P14 which is equivalent to *Truncorotaloides rohri* Zone P14 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

**_Truncorotaloides topilensis_ (Cushman) 1925**

Pl. 12, Figs. 7-12

***Synonymy:*** *Globigerina topilensis* Cushman: 1925 7, Pl. 1, Figs. 9a-c.
*Truncorotaloides topilensis* (Cushman) –BOLLI 1957b, p. 170, Pl. 39, Figs. 13-16. - RAJU 1968, p.290, Pl. 2, Figs. 9a-c. – BLOW 1969, p. 373, Pl. 51, Figs. 1-3. - SAMANTA 1970, p.215, Pl. 3, Figs. 22,23. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 234, Fig. 91, nos. 1-7.

***Material:*** Twenty-four specimens in samples WME-147 and WME-148.

***Description:*** Test distinctly angular in shape with two chambers in the last whorl which increase rapidly in size as added and become trumpet shape. Coarse spinose ornamentation and extreme late ral flattening in the last whorl.

***Dimensions:*** (in mm) Two described specimens were measured here from sample WME-148 (Pl. 12, Figs. 7-12).

| | MAXIMUM | MINIMUM | AVERAGE |
|---|---|---|---|
| DIAMETER | 0.41 | 0.38 | 0.39 |
| HEIGHT | 0.22 | 0.19 | 0.20 |
| H/D | 0.54 | 0.50 | 0.52 |

***Remarks:*** The main variation shown within the Omani material is in the shape of the test, the angle of attachment of the last chamber and the outline of the periphery. The Oman specimens are almost identical to those illustrated by Bolli (1957b) from the *Orbulinoides beckmanni* Zone of Trinidad, and those of Samanta (1970) from western India. *Truncorotaloides topilensis* differs from all other Lower Tertiary planktonic Foraminifera in the flattened bun shape of its youngest (late st) chambers. *T. topilensis* differs from *T. rohri* in its angular profile accentuated by spines. *T. topilensis* shows similarity to *T. haynesi* (Samanta, 1970) and *T. libyaensis* (El-Khoudary, 1977) in the shape of its chambers, but the latter both have 5-6 chambers in the last whorl whilst *T. topilensis* has 4 chambers in the last whorl.

***Geographical distribution and stratigraphical range:*** *Truncorotaloides topilensis* was originally described from the Middle Eocene of eastern Mexico. Raju (1968) has reported it from southern India and Samanta (1969; 1970) recorded it from the Middle Eocene of eastern and western India. Samanta (1973) also reported it from the Middle Eocene Raki Nala section in the western Punjab, Pakistan. It is also found in Trinidad Bolli (1957b) ranging from the *Globigerinapsis kugleri* Zone to *Orbulinoides beckmanni* Zone.

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with, *Morozovella edgari*, *Globigerinatheka euganea* and *Turborotalia blowcentralis* nom. nov. indicating a Middle Eocene age within the *Truncorotaloides topilensis/Morozovella edgari* Zone P10 which is equivalent of P10 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

| SPECIES | TEST | | PERIPHERY | CHAMBERS [illegible] | | UMBILICUS | SUTURES | APERTURE | DISTINGUISHING FEATURES | AGE |
|---|---|---|---|---|---|---|---|---|---|---|
| | size | shape | | number | shape | | | | | |
| *Truncorotaloides libyaensis* | Medium | Subrectangular | Rectangular | 5 | Subangular | Deep and wide | Radial, curved to slightly straight | Low arch | Subrectangualr shape, rectangular periphery and low arch aperture with liplike border | M-Late Eocene |
| *Truncorotaloides topilensis* | Large | Angular | Lobate | 4 | Inflated | Deep and narrow | Deep and incised | Well-formed arched | Distinct angular shape, trumpet shaped and the angle of attachment of the last chamber | Middle Eocene |

Fig. 4.8 Summary of key morphological features of studied planktonic foraminifera (*Truncorotaloides*).

**Genus *Turborotalia* Cushman and Bermudez 1949**

Test subglobular, trochospiral. Periphery noncarinate; chambers ovate or rounded; sutures commonly depressed; wall finely perforate, surface smooth to hispid; aperture interiomarginal, extraumbilical-umbilical, with bordering lip (Fig. 4.9). Age range from Early Eocene (Danian), from the base of *Acarinina pentacamerata* Zone (P9) to Recent.

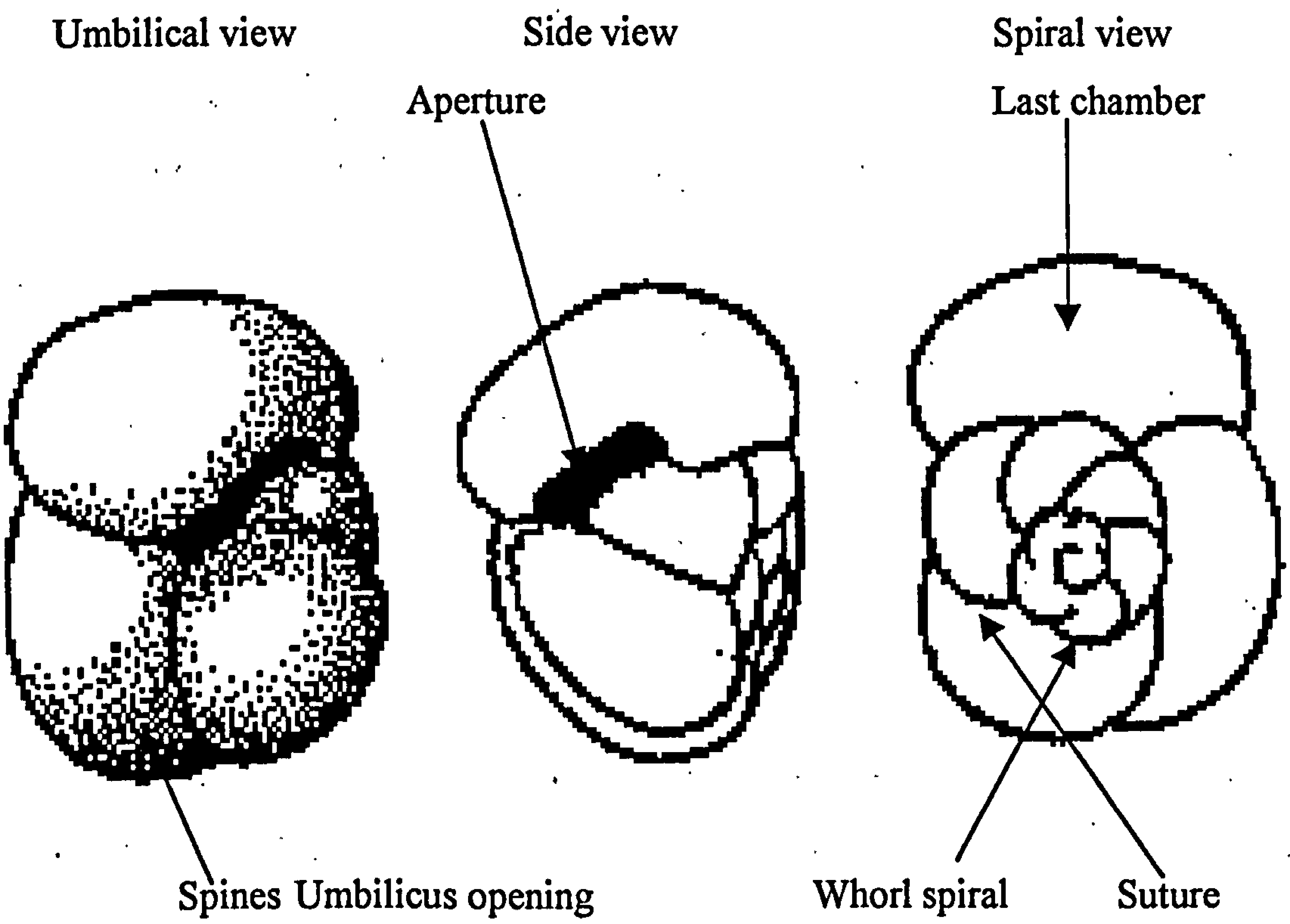



**Fig. 4.9 Morphology of *Turborotalia* (modified from Banner 1982)**

TYPE SPECIES *Globorotalia centralis* Cushman and Bermudez, 1937

***Turborotalia blowcentralis* nom. nov..**

[Pro *G. (T) praecentralis Blow,* 1979; not Haque, 1966]

Pl. 13, Figs. 4-6

*Synonymy: Globorotalia (Turborotalia) praecentralis* Blow, 1979, p.1094-1096, Pl. 135, figs .7-9. Pl. 136, figs 1-6, Pl. 233, Fig. 6. (not *Globorotalia praecentralis* Haque, 1966).

*Turborotalia blowcentralis nom. nov.* (Blow), TOUMARKINE and LUTERBACHER

1985, p. 136, Fig. 34, no. 14-16.

*Material:* Five specimens in sample WME-148 from the Musawa Formation, Wadi Musawa Section SE Oman Mountains.

*Description:* Test low trochospiral with a rounded to subrounded periphery. Spiral side almost flat to slightly convex at proloculus. Umbilical side strongly convex, with shallow and narrow, open umbilicus. There are 4-5 chambers which increase moderately in size and become subrounded to rounded in the last whorl. High arch-shaped aperture. Test surface covered by fine spines. Sutures depressed to slightly curved on spiral side, deep and almost radial on umbilical side.

*Dimensions:* (in mm) Based on figured specimen (Pl. 13, Fig. 4-6).

| | |
|---|---|
| DIAMETER | 0.4 |
| HEIGHT | 0.3 |
| D/H | 0.7 |

*Remarks: G.* (*T*) *praecentralis* Blow 1979 is a primary homonym of *G. praecentralis* Haque, 1966, and must thus be given new name. I propose the name *blowcentralis* the name of Sir Walter Blow. Similar to *Turborotalia bella* (Jenkins 1971: Pl. 11, Figs. 270-272) in terms of its rounded periphery, test shape and number of chambers in the last whorl. It differs however in having a high arched aperture, whilst *T. bella* has a low slit with thick lip. It also shows affinity with *Turborotalia centralis* and *T. cerroazulensis* but differs in having a flat spiral side and more subrounded chambers in the last whorl on the umbilical side.

*Geographical distribution and stratigraphical range: Turborotalia blowcentralis* nom. nov. is previously unknown.

*Local range and faunal associations:* Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Truncorotaloides topilensis*, *Globigerinatheka euganea* and *Morozovella edgari* indicating a Middle Eocene age within the *Truncorotaloides topilensis/Morozovella* *edgari* Zone (P10) which is equivalent of the (P10) of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

| SPECIES | TEST | | PERIPHERY | CHAMBERS | | UMBILICUS OPEN | SUTURES | APERTURE | DISTINGUISHING FEATURES | AGE |
|---|---|---|---|---|---|---|---|---|---|---|
| | size | shape | | number | shape | | | | | |
| *Turborotalia blowcentralis* nom. nov. | Large | Subtriangular | Rounded/Subrounded | 4 to 5 | Subrounded | Shallow and narrow | Depressed to radial | High arch-shaped | Rounded periphery, narrow and shallow umbilicus and high arch-shaped aperture | Middle Eocene |

**Fig. 4.10 Summary of key morphological features of studied planktonic foraminifera (*Turborotalia*).**

**Genus *Hastigerina* Thomson in Murray 1876**

Test free, early stage may be slightly trochospiral, involute to loosely coiled; periphery broadly rounded; chambers spherical to ovate; sutures deeply depressed, radial; wall fine to coarsely perforate, surface smooth, hispid, or spinose; aperture interiomarginal, broad equatorial arch. Age range from upper part of Early Eocene (Ypresian), from the base of *Acarinina pentacamerata* Zone (P9) to Recent.

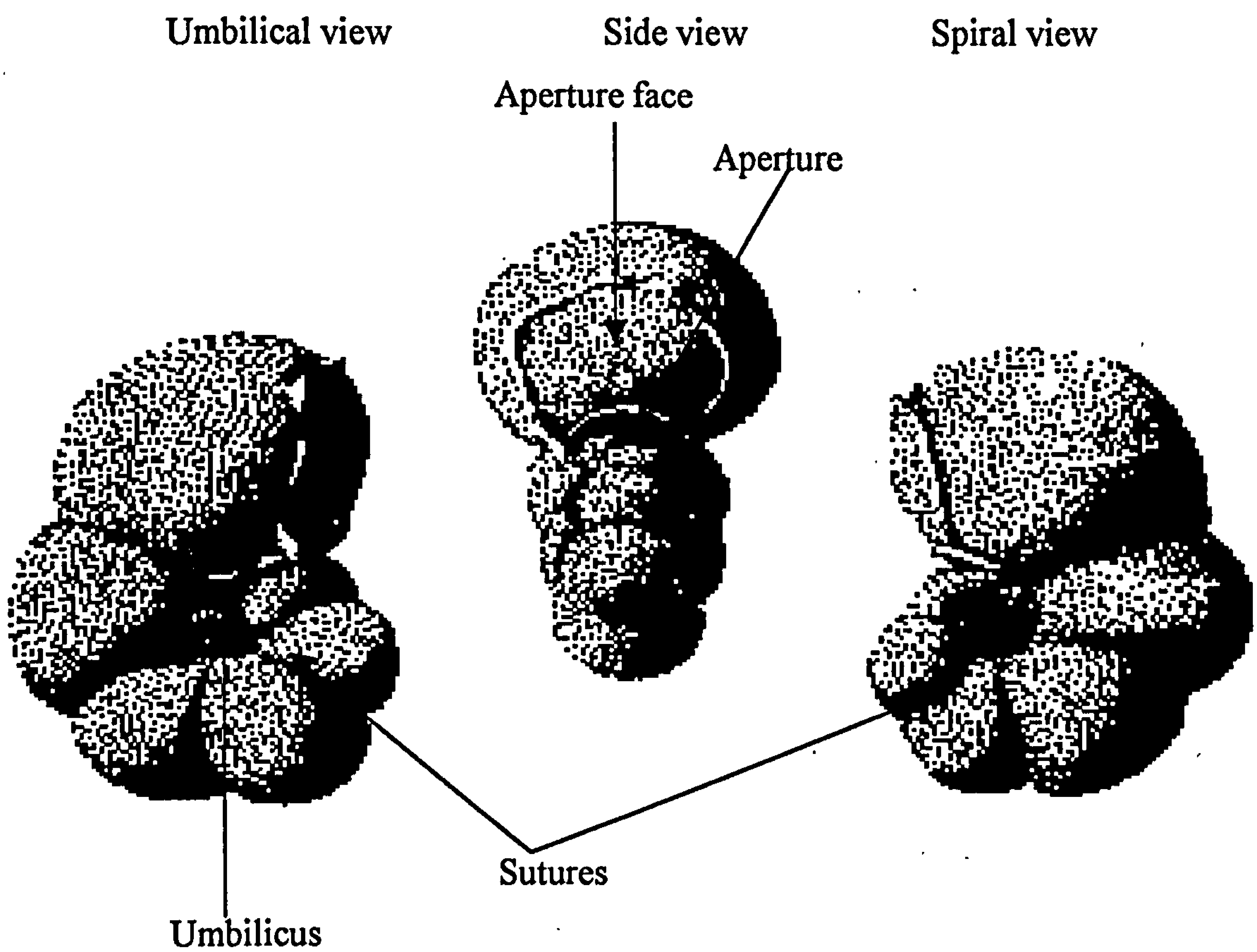



**Fig. 4.11 Morphology of *Hastigerina* (modified from Banner, 1982).**

***"Hastigerina" sp.***

Pl.13, Figs. 7-12

***Material:*** Thirty-three specimens in sample WME-94.

***Description:*** Test globular, tightly coiled, slightly asymmetrical with a rounded periphery. There are 4-5 chambers in the last whorl with the last chamber occupying

2/3 of the last whorl. Surface coarsely spinose. Sutures curved in the early whorls and nearly straight in the last whorl. Aperture a low arched opening with a faint lip. The main variation within the present specimens is in the number of chambers in the last whorl (3.5 to 5), shape and size (0.34 to 0.37 mm) of the test and size of the spines from 0.05 to 0.07 mm.

***Dimensions:*** (in mm) Based on 2 figured specimens (Pl. 13, Fig. 7-12).

| | MAXIMUM | MINIMUM | AVERAGE |
|---|---|---|---|
| DIAMETER | 0.37 | 0.34 | 0.35 |
| HEIGHT | 0.23 | 0.20 | 0.21 |
| H/D | 0.62 | 0.58 | 0.60 |

***Remarks:*** Similar forms have been referred to '*Hastigerina*' cf. *bolivariana* and "*Hastigerina*" *bolivariana* (Petters) by Toumarkine and Luterbacher (1985, pages 126, 127, Fig. 27). Generic assignment follows that paper ("*Hastigerina*"), but these forms are completely different from the true Neogene *Hastigerina*.

***Geographical distribution and stratigraphical range:*** Previously unknown from Oman.

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella abundocamerata, M. formosa formosa, M. gracilis,* and *Acarinina pentacamerata* indicating an early Eocene age. This species is found within the *Acarinina pentacamerata* Zone P9, which is equivalent to P9 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

| SPECIES | TEST | | PERIPHERY | CHAMBERS | | UMBILICUS | SUTURES | APERTURE | DISTINGUISHING FEATURES | AGE |
|---|---|---|---|---|---|---|---|---|---|---|
| | size | shape | | number | shape | | | | | |
| *Hastigerina sp.* | Medium | Globular | Rounded | 4 to 5 | Subglobular | Very narrow | Curved to nearly straight | Low arched opening with faint lip | Globular shape, asymmetrical with rounded periphery and coarsely spinose surface | Early Eocene |

**Fig. 4.12 Summary of key morphological features of studied planktonic foraminifera (*Hastigerina*).**

**Genus *Globigerinatheka* Bronnimann, 1952**

*[Description used here is that of Proto Decima and Bolli, 1970]*

Test globular to subglobular, early chambers trochospiral, as in *Globigerina*, late r with a large enveloping final chamber covering previous umbilical area formed by the previous chambers. Sutures depressed, radial. Wall calcareous perforate, radial in structure. Primary aperture interiomarginal, umbilical, but covered in adult by final enveloping chamber, secondary sutural apertures on spiral side, covered by small bullae, each with one or more infralaminal accessory apertures. Age range from Middle Eocene (Basal Lutetian), from near base of *Hantkenina nuttalli* Zone (P10) to Late Eocene (Priabonian), top of *Turborotalia cerroazulensis* Zone (P17) Blow (1969) and Berggren and Van Couvering (1974).

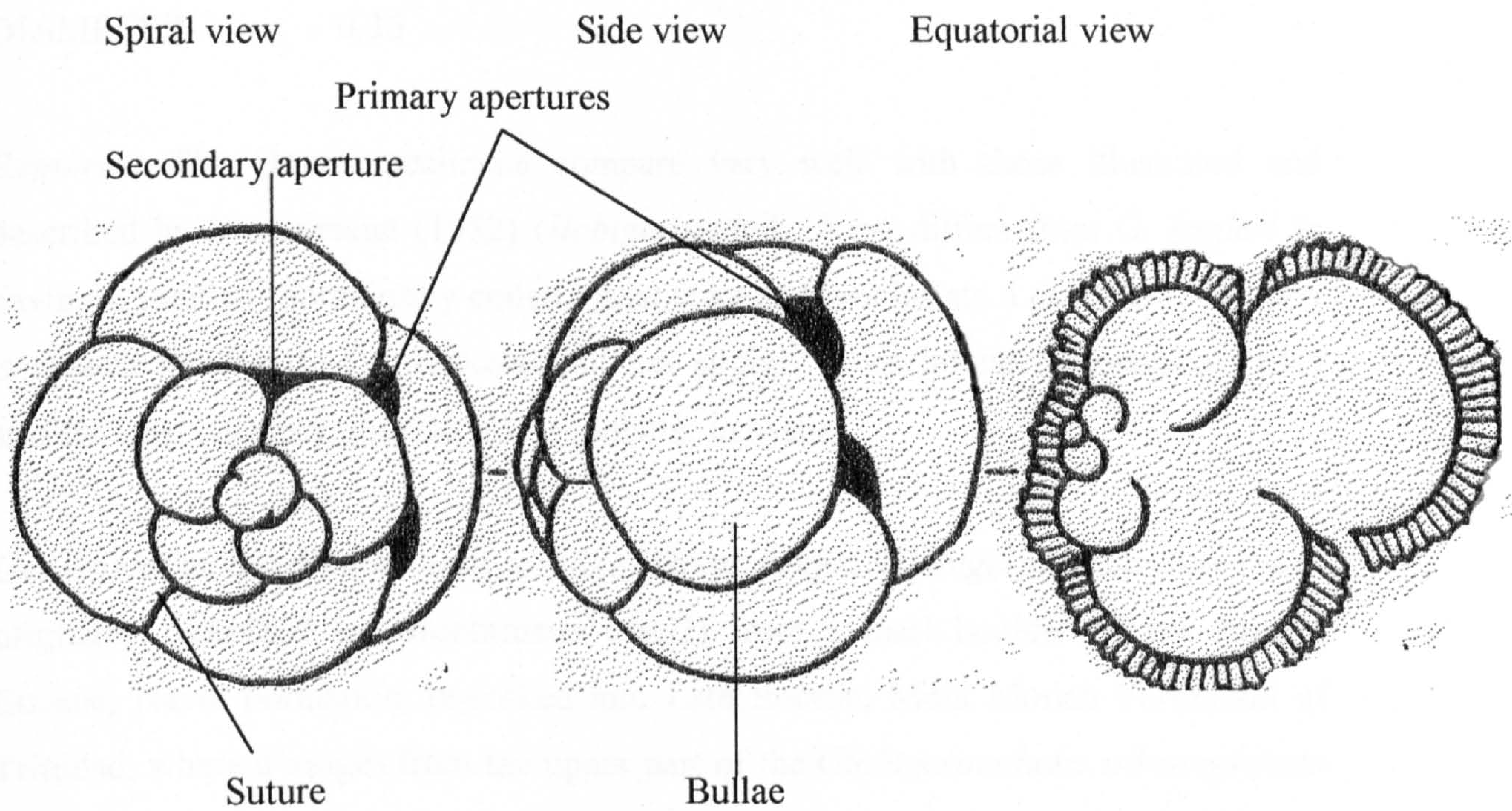



**Fig. 4.13 Morphology of *Globigerinatheka* (modified from Banner, 1982).**

TYPE SPECIES *Globigerinatheka barri* Bronnimann, 1952

***Globigerinatheka barri* Bronnimann, 1952**

Pl.14, Figs. 1-3

***Synonymy:*** *Globigerinatheka barri* Bronnimann 1952, p. 27-28, text-Figs. 3a-c, g-h, text-Figs. 3d-f.- BOLLI, LOEBLICH and TAPPAN 1957, p. 38, Pl. 7, Fig.12, -

BOLLI 1957c, p. 166, Pl.57, Figs. 8-9. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 170-171, Fig. 37, nos. 1-6.

*Material:* Twelve specimens in sample WME-183.

*Description:* Test small, subglobular, tightly coiled initial spire with globular chambers in the early coil which enlarge moderately in size as added. There are 3 inflate d chambers with the final chamber large and embracing most of the umbilical area formed by earlier chambers. Wall coarsely perforate. Sutures deeply incised and slightly curved. Aperture an interiomarginal, umbilical arch.

*Dimensions:* (in mm) Figured specimen was measured (Pl. 14, Figs. 1-3).

DIAMETER 0.36

*Remarks:* The Oman specimens compare very well with those illustrated and described by Bronnimann (1952) *Globigerinatheka barri* differs from *G. kugleri* in having a smaller, more tightly coiled initial spire and less inflate d chambers. *G. barri* is closely relate d to *G. mexicana* but has slightly more inflate d chambers and a smaller final chamber, making it less globular in shape.

*Geographical distribution and stratigraphical range: Globigerinatheka barri* was originally described by Bronnimann (1952) from a marl boulder of the Middle Eocene, Navet Formation, reworked into Late Eocene, Mont Moriah Formation of Trinidad, where it ranges from the upper part of the *Globigerinatheka subconglobata* Zone to the base of the lower part of the *Globigerinatheka semiinvoluta* Zone. Samanta (1973) reported it from Pakistan and assigned it to the *Globorotalia crassata/Truncorotaloides topilensis* and *Truncorotaloides rohri* Zones.

*Local range and faunal associations:* Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Truncorotaloides topilensis* and *Globigerinatheka* sp. B in strata of presumed Middle Eocene age within the *Globigerinatheka barri* Zone P12, which is equivalent to P12 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

**_Globigerinatheka_ cf. _curryi_ Proto Decima and Bolli, 1970**

Pl.14, Figs. 4-6

*Synonymy*: See *Globigerinatheka curryi* PROTO DECIMA and BOLLI 1970, p. 889-894, Pl. 1, Figs. 1-4, Pl. 3, 1-2, text-Figs. 1-3a, 38-39b.

*Material:* Nine specimens in sample WME-186.

*Description:* Test globular to subglobular with globular chambers which increase moderately in size towards the end of the last whorl. Three chambers are present in the last whorl. Sutures are deep and incised to slightly curved between the chambers in the last whorl. Large bullae are present. Coarse perforations with reticulate ornament. Aperture is not obvious.

*Dimensions:* (in mm) Figured specimen was measured (Pl. 14, Fig. 4-6).

| | |
|---|---|
| DIAMETER | 0.36 |
| HEIGHT | 0.31 |
| H/D | 0.86 |

*Remarks:* The figured specimen (Pl. 14, Fig. 4-6) may be compared with the holotype which also has characteristic coarse perforation. However, the Oman specimen is smaller in size and has less chambers (three) in the early stage than *Globigerinatheka curryi* Proto Decima and Bolli (1970) as originally described. Both show similar coarse perforation. According to the original authors *Globigerinatheka curryi* differs from *G. euganea* in having more strongly incised sutures, more strongly inflate d chambers and consequently a less spherical test shape. *Globigerinatheka curryi* is similar to *G. kugleri* (Loeblich and Tappan, 1957), but differs in the number of chambers in the last whorl (4 chambers in *G. kugleri), G. kugleri* is also smaller in size.

*Geographical distribution and stratigraphical range: Globigerinatheka curryi* was originally described by Decima and Bolli (1970) from the Middle Eocene of Trinidad where it occurs in the *Hantkenina nuttalli* and *Globorotalia lehneri* Zones. Also occurs in southern India (Samanta 1970) in the Upper Palaeocene of the Pondicherry Formation.

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Truncorotaloides topilensis, Truncorotaloides libyaensis, Globigerinatheka curryi, Morozovella bolivariana* and *Neorotalia omanensis nov.* indicating a Middle Eocene age. This species is found within the *Truncorotaloides topilensis/Morozovella bolivariana* Zone P13 on the basis of the local range.

### *Globigerinatheka euganea* Proto Decima and Bolli, 1970

Pl.14, Figs. 7-8

***Synonymy:*** *Globigerinoides mexicana* sensu BECKMANN 1953 (not *Globigerina mexicana* Cushman, 1925a).
*Globigerinatheka euganea*, PROTO DECIMA and BOLLI 1970, p.63, no. 3, Pl. 25, Figs.15,16.

***Material:*** Three specimens in sample WME-148.

***Description:*** Test subspherical, tightly coiled with three larger chambers in the last whorl. Distinct bullae with a very coarsely perforate wall. The last chamber extends over the umbilical area.

***Dimensions:*** (in mm) Based on figured specimen (Pl. 14, Figs. 7-8).
DIAMETER 0.4

***Remarks:*** The Oman specimens are smaller in size than *Globigerinatheka euganea* described by Proto Decima and Bolli (1970: Pl. 1, Fig. 7). According to Proto Decima and Bolli (1970) *Globigerinatheka euganea* is intermediate in form between its ancestor *G. curryi* and successor *Orbulinoides beckmani*. The Oman material strongly supports this suggestion.

***Geographical distribution and stratigraphical range:*** *Globigerinatheka euganea* was originally described by Proto Decima and Bolli (1970) from Trinidad where it occurs in the Middle Eocene *Globorotalia lehneri* and *Orbulinoides beckmanni* Zones.

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Truncorotaloides topilensis, Morozovella edgari, Globigerinatheka euganea and Turborotalia blowcentralis* nom. nov. indicating a Middle Eocene age within the *Truncorotaloides topilensis/Morozovella edgari* Zone P10 on the basis of the local range.

### *Globigerinatheka subconglobata subconglobata* Shutskaya, 1958

Pl. 14, Figs. 9-10

***Synonymy:*** *Globigerinatheka subconglobata subconglobata* Shutskaya 1958, p. 86-87, Pl. 1, Figs. 4-11. - BOLLI, 1972, p. 134, Figs. 43-46, Pl. 1, Figs. 8-10, 15-16. – STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS 1975, p. 230-231, Fig. 90, no. 4.

***Material:*** Seven specimens from sample WME-76.

***Description:*** Test large, almost spherical. There are 3 chambers in the last whorl which embraces the umbilical side of the earlier coil. Sutures deep and depressed. Apertures sutural, small and low. Test surface covered by short pustules and finely perforated.

***Dimensions:*** in mm The described and illustrated specimen was measured (Pl. 14, Figs. 9-10).

DIAMETER 0.39

***Remarks:*** The Oman specimen compares very well with the specimen described and illustrated by Bolli (1972), and is slightly larger than type specimen.

*Globigerinatheka subconglobata subconglobata* is placed in the synonymy with *G. index index* by Subbotina (1971) who used a very broad species concept. However, *Globigerinatheka subconglobata subconglobata* differs from *Globigerinatheka index index* in having a more compact test and smaller apertures.

***Geographical distribution and stratigraphical range:*** *Globigerinatheka subconglobata subconglobata* was originally described by Bolli (1972) from the Middle Eocene of the northern Caucasus. Stainforth *et al.*, (1975) place *Globigerinatheka subconglobata subconglobata* within the *Hantkenina aragonensis* Zone to within the *Orbulinoides beckmanni* Zone. It is also found in the northern Italy (Bolli, 1972) from the early Middle Eocene *Globigerinatheka subconglobata* Zone.

***Local range and faunal associations:*** Previously unknown from Oman. Found in the Wadi Musawa section of the SE Oman Mountains in association with *Morozovella centralis, M. caucasica, Subbotina quadrata* and *Subbotina triangularis* indicating an early Eocene age within *Morozovella aragonensis* Zone which is equivalent to P8 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Globigerinatheka* sp. A**

Pl.14, Figs. 11-12

***Material:*** Common in sample WME-183.

***Description:*** Test free, early whorl slightly flat with four chambers in the last whorl. Wall coarsely perforate. Sutures deep and curved especially between chambers in the earlier whorls. Two to three openings visible between chambers. Chambers increasing in size towards the last whorl.

***Dimensions:*** (in mm) Figured specimen was measured (Pl. 14, Figs. 11-12).

DIAMETER 0.4

***Remarks:*** The Omani species is similar to *Globigerinatheka barri* but lacks the bullae of the latter. *Globigerinatheka kugleri* is similar but differs mainly in having fewer chambers per whorl and a slightly different test shape. The Omani species appears to be intermediate between *G. kugleri* and *G. index.*

***Geographical distribution and stratigraphical range:*** Previously unknown.

***Local range and faunal associations:*** *Globigerinatheka* sp. A was found in the Wadi Musawa section of the SE Oman Mountains in association with *Globigerinatheka barri* and *Truncorotaloides topilensis* considered to be of Middle Eocene age. This species is found within the *Globigerinatheka barri* Zone P12, which is equivalent to *Morozovella lehneri* Zone P12 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

### ***Globigerinatheka* sp. B**

Pl. 15, Figs. 1-2

***Material:*** Four specimens from sample WME-186.

***Description:*** Test spherical to subspherical with finely perforate and reticulate wall. *Globigerina*-like in early stages with a late r enveloping, inflate d, globular chamber. Sutures depressed and curved.

***Dimensions:*** (in mm) Figured specimen was measured (Pl. 15, Figs. 1-2).

DIAMETER 0.4

***Remarks:*** Additional material may clarify the taxonomic position of this species, which currently assigned to *Globigerinatheka* sp.

***Geographical distribution and stratigraphical range:*** Previously unknown from Oman.

***Local range and faunal associations:*** Found in the Wadi Musawa section of the SE

Oman Mountains in association with *Globigerinatheka curryi Morozovella bolivariana* and *Truncorotaloides libyaensis* indicating a Middle Eocene age. This species is found within the *Truncorotaloides topilensis/bolivariana* Zone P13 on the basis of local rang Zones.

| SPECIES | TEST | | CHAMBERS (In the last whorl) | | SUTURES | APERTURE | DISTINGUISHING FEATURES | AGE |
|---|---|---|---|---|---|---|---|---|
| | size | shape | number | shape | | | | |
| *Globigerinatheka barri* | Medium | Subglobular | 3 | Inflated | Deeply incised and curved | Intermarginal, umbilical arch | Subglobular shape, deep sutures and intermarginal aperture | M-Late Eocene |
| *Globigerinatheka curryi* | Medium | Globular to subglobular | 3 | Globular | Deep and incised | Not obvious | Subglobular to globular shape, large bullae and reticulate ornament | M-Late Eocene |
| *Globigerinatheka eugania* | Large | Subspherical | 3 | Spherical | Deep and curved | Not obvious | Subspherical shape and distinct bullae with coarse perforated wall | Middle Eocene |
| *Globigerinatheka sub. Subconglobata* | Medium | Spherical | 3 | Globular | Deep and depressed | Sutural small and low | Spherical shape, globular chambers and sutural apertures | Early Eocene |
| *Globigerinatheka sp. A* | Large | Subspherical | 4 | Globular | Deep and curved | Small openings between chambers | Subspherical shape and several openings between chambers | M-Late Eocene |
| *Globigerinatheka sp. B* | Large | Spherical | Not clear | Globular/Inflated | Depressed and curved | Not obvious | Spherical shape, reticulate wall and depressed to curved sutures | M-Late Eocene |

**Fig. 4.14 Summary of key morphological features of studied planktonic foraminifera (*Globigerinatheka*).**

**4.3 Cretaceous Reworking**

Below sample WM1 a number of reworked Cretaceous planktonic Foraminifera were recovered. The assemblages comprised: *Globotruncana mariei, Globotruncana rosetta, Heterohelix globulosa, Heterohelix labellosa, Planohedbergella voluta, Rugoglobigerina rugosa, Rugoglobigerina hexacamerata, Rugoglobigerina perryi* and *Trinitella scotti* and was determined by Lynne Allen. Selected key taxa are illustrated on Pl. 17, Figs. 7-12. This assemblage is dated as Companion to Maastrichtian based on the co-occurrence of the taxa *Globotruncana mariei, Planohedbergella voluta* and *Rugoglobigerina rugosa.*

These occur in association with clearly Late Palaeocene planktonic assemblage comprising *Morozovella angulata* and *Subbotina triloculinoides.* Consequently, although not now present in the immediate study area Late Cretaceous (Campanion to Maastrichtian) deep marine sediments were once deposited in the area and were reworked in the Late Palaeocene .

# Chapter Five
# Larger Foraminifera

# *Chapter Five*

# SYSTEMATIC PALAEONTOLOGY
# LARGER FORAMINIFERA

## 5.1 INTRODUCTION

The larger Foraminifera generally include species over 2mm diameter whose internal features can often be used for age determination which often requires that the test be sectioned. For practical purposes there is no difference between larger and smaller Foraminifera apart from the fact that most of the larger Foraminifera require careful orientated sectioning described under methodology (Chapter One).

Larger Foraminifera occur in the limestones and, often as matrix-free material in softer lithologies such as marls and shales which are often redeposited, (penecontemporaneously) into deeper-water. Where the larger Foraminifera cannot be separated from hard limestone only random thin sections can generally be studied, with the disadvantage that accurate species determination can be difficult or impossible. Occasionally individual specimens can be cut out of hard limestones and oriented thin sections cut but this is very time consuming.

The larger Foraminifera were studied mainly to infill "biostratigraphical" gaps where planktonic Foraminifera were absent in the Wadi Musawa and Wadi Suq sections, and to supplement the age determinations given by the planktonics. They also provided important palaeoecological information in the constantly changing environments of the Omani Palaeogene.

Twenty seven species and two subspecies of larger Foraminifera belonging to twelve genera including *Alveolina, Asterocyclina, Coskinolina, Daviesina, Dictyoconus, Discocyclina, Gypsina, Lepidocyclina, Linderina, Miscellanea, Neorotalia, Nummulites* and *Operculina* were studied in axial and equatorial section. One hundred and twenty oriented sections and two hundred and sixty five random thin sections were prepared by the present author and only the well-preserved and best specimens were used for species determination.

Groups such as nummulitids were identified using Racey (1988 and 1995), Schaub (1981) and Samanta (1990), whilst White (1989) and Hottinger (1962) were used for the identification of the alveolinids and Samanta (1985) to identify the discocyclinids. Generally the larger Foraminifera are poorly preserved internally due to having been redeposited. They are often infilled with pyrite occasionally silicified and/or bored and are thus, difficult to section, photograph (even when the best specimens were chosen, see Plates 19-23), and, identify. For this reason many of the larger Foraminifera described herein are left in open nomenclature. However, two species are considered important enough to warrant formal description as new: *Operculina musawaensis* and "*Neorotalia*" *omanensis*.

**Family NUMMULITIDAE de Blainville, 1827**
**Subfamily NUMMULITINAE Carpenter, 1850**
**Genus *Nummulites* Lamarck, 1801**

TYPE SPECIES *Nummulites* laevigatus Bruguiere, 1792

***Nummulites* cf. *atacicus* Leymerie, 1846**

Pl. 19, Fig. 3.

***Material***: A single uncentred axial section of an A-form from sample WME 94.

***Diagnosis***: This species is characterised by its lenticular test with radiating thin pillars clustered around the pole and by its uniformly opening regular spire.

***Dimensions***: in mm

| | |
|---|---|
| Diameter | 2.10 |
| Height | 1.01 |
| H/D | 0.48 |

***Remarks***: Racey (1995) noted that this species was difficult to identify due to its similarity to *Nummulites praecursor*, which according to Schaub (1981) was its ancestor. Generally, it is slightly larger with more chambers and regular septa than *N. praecursor*. It is also often confused with *Nummulites globulus* (Lower Eocene) and

*Nummulites discorbinus* (Middle Eocene) from which it is distinguished by its larger proloculus and more chambers per whorl.

***Geographical distribution and stratigraphical range***: France (Leymerie 1846), Austria (Papp 1959), Libya (Silvestri 1928), Algeria (Flandrin 1938), Syria (de Cizancourt 1934), U.S.S.R. (Nemkov 1967), Somalia (Silvestri 1939), Madagascar (Doncieux 1948), India (Nuttall 1925) and Oman (Racey 1988 and 1995).

***Local range and faunal associations***: *Nummulites* cf. *atacicus* is found in the Wadi Musawa section in association with *Morozovella formosa formosa* and *Morozovella gracilis* indicating an Early Eocene age within the *Morozovella marginodentata* Zone (P8), which is equivalent to the *Morozovella aragonensis* Zone (P8) of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Nummulites discorbinus* Shlotheim, 1820**

Pl. 22, Figs. 1

***Synonymy***: *Nummulites discorbinus* Schlotheim RACEY 1995, p. 41-42, Pl. 2, Figs. 29-31. *cum syn.*

***Material***: Seven random sections specimens, and one equatorial section from sample WME 148.

***Diagnosis***: A-form: Inflated test with fairly sharp periphery, thick marginal cord; septa slightly inclined and gently curved; with subrectangular arcuate chambers 1.2x higher than long. Proloculus small 0.10-0.18mm.

***Dimensions***: A-form: 2.1mm in diameter.

Equatorial section A-form

| Whorl | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Radius (mm) | 0.6 | 0.9 | 1.3 | 1.7 | 2.1 | 2.6 |
| Chambers | 9 | 19 | 23 | 26 | 27 | 33 |

***Remarks***: The present specimen is similar to those described by Schaub (1981), Lahiri (1985) and Racey (1995). *Nummulites discorbinus* is often confused with *N. beaumonti* however, the former is distinguished by its smaller test, longer chambers and thicker marginal cord.

***Geographical distribution and stratigraphical range***: Somalia (Silvestri, 1939), India (Nuttall, 1926), Adriatic (Blondeau, 1972a), Egypt (d'Archiac and Haime, 1853), Italy (Checchia-Rispoli, 1925), Spain (Schaub, 1981), Qatar (Smout, 1954; Cavelier, 1970), Eastern Saudi Arabia (Sander, 1962) and Oman (Racey, 1995). The species ranges from Middle Lutetian to early Biarritzian in the Northern Oman Mountains (Racey, 1995).

***Local range and faunal associations***: Found in Oman at Wadi Musawa in association with *Truncorotaloides topilensis*, *Globigerinatheka euganea*, *Morozovella edgari*, and *Turborotalia blowcentralis* nov. nov. indicating a Middle Eocene age within the Truncorotaloides topilensis/*Morozovella edgari* Zone P10, which is equivalent to *Hantkenina nuttalli* Zone P10 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

*Nummulites fichteli* **Michelotti, 1841**

Pl. 19, Fig. 8

***Synonymy***: [*Fide*] *Nummulites fichteli* Michelotti - RACEY 1995 p. 44, Pl. 4, Figs. 1-7. *cum syn.*

***Material***: Three specimens in random thin sections from sample WS 106, Wadi Suq.

***Diagnosis***: Lenticular flattened test, with rounded periphery with distinct pillars from poles to periphery and with distinctive highly reticulate septal filaments. Marginal cord fairly thick. Proloculus is about 0.21mm in diameter.

***Dimensions***: (in mm). Only A-form measured approximately 4.7mm in diameter and 1.4mm thick and comprises at least 6-7 whorls in a radius of 1.9mm.

***Remarks***: Commonly confused with *Nummulites fabiani* however *Nummulites fichteli* has a larger flatter test, better developed reticulate septal filaments and a more uniform spire.

***Geographical distribution and stratigraphical range***: This species is widely distributed throughout the Mediterranean and Indo-West Pacific being recorded from India (Nuttall, 1925), Somaliland (Nuttall and Brighton, 1931), Madagascar (Doncieux, 1948), Indonesia (Adams, 1967), U.S.S.R (Nemkov, 1967), Mediterranean (Blondeau, 1972), Middle East (Montenat *et al*., 1977), India (Lahiri, 1985) and Oman (Racey, 1988 and 1995).

***Local range and faunal associations***: Previously recorded by Racey (1988 and1995) from the Ma'ahm beds of Wadi Rusayl, northern Oman Mountains within the *N. fitcheli* zone (Early to mid-Oligocene). Here it occurs in association with *Lepidocyclina* (*Eulepidina*) indicating a mid-Oligocene age.

***Nummulites fossulata*** **de Cizancourt, 1938**

Pl. 20, Fig. 4

***Synonymy***: *Nummulites fossulata* de Cizancourt - RACEY 1995, p. 45, Pl. 1, Figs. 24-26. *cum syn.*

***Material***: A single A-form axial specimen from a random thin section of sample WM 43 Wadi Musawa section.

***Diagnosis***: Characterised by a small, lenticular test with a sharp periphery, and marked by a central depression surrounded by small pillars giving the appearance of an angular "dumb-bell" in axial section.

***Dimensions***: in mm only one axial specimen measured.

| | |
|---|---|
| Diameter | 1.80 |
| Height | 0.90 |
| H/D | 0.50 |

***Remarks***: This species is very distinctive in axial section and is slightly thicker then those described by Racey (1995).

***Geographical distribution and stratigraphical range***: Previously recorded from the Lower Eocene of Afghanistan by de Cizancourt (1938) and from the Late Cuisian to earliest Lutetian of Oman (Racey 1988 and 1995) where it ranges through the *N. campesinus* and *N. gallensis* zones of Schaub.

***Local range and faunal associations***: Found in the Wadi Musawa Section, within Unit D, between *Acarinina soldadoensis* Zone (P6) and *Globigerinatheka subconglobata subconglobata* Zone (P7), and is considered to be an Early Eocene age.

**_Nummulites_ sp. aff. _N. globulus_ Leymerie, 1846**

Pl. 20, Fig. 1

***Material***: Two specimens in random thin section from sample WM 34 both axial sections of A-form.

***Diagnosis***: A-form: Characterised by a small lenticular, inflated to globular test with a sharp periphery and thick polar pillar. Spire compact, regular. Proloculus small, about 0.16mm, subcircular in outline. The wall of the last whorl is thinner than in earlier whorls.

***Dimensions***: in mm

| | |
|---|---|
| Diameter | 1.80 |
| Height | 0.82 |
| H/D | 0.45 |

***Remarks***: The present specimen shows some similarities to those described by Racey (1995), from Wadi Amq, Northern Oman Mountains.

***Geographical distribution and stratigraphical range***: *Nummulites globulus* was previously recorded from the Mediterranean (Blondeau 1972; Schaub 1981), USSR (Nemkov 1967), Qatar from lower Eocene (Smout 1954), Afghanistan (Carbonnel and Blondeau 1977), Algeria (Flandrin 1938), Somaliland (Azzaroli 1952), Egypt (Hamam 1975), France (Douville 1919), India (Davies and Pinfold 1937) and in Oman it ranges from Middle 2 Ilerdian to Early Cuisian according to (Racey 1995). Schaub (1981) suggests that this species ranges from Middle Ilerdian to Upper Ilerdian in the Mediterranean region.

***Local range and faunal associations***: Found in the Abat Formation of the Wadi Musawa Section in association with *Operculina musawaensis* sp. nov. and *Actinocyclina* sp. at the base of *Acarinina soldadoensis* zone (P6), which is equivalent to the *Morozovella subbotinae* zone (P6) of Blow (1969; 1979) and Berggren *et al.* (1988) respectively. Therefore, in the present study it is assigned to the Early Eocene (Ypresian).

***Nummulites* cf *honogoensis* Hanzawa, 1964**

Pl. 19, Figs. 1-2

***Material***: Two specimens one axial and one equatorial from sample WM 31a.

***Diagnosis***: Medium sized thick lenticular test with blunt periphery. There are six whorls with 26-29 rectangular chambers in the last whorl in the B-form. Sutures are straight gently recurved towards the periphery with fairly a thick marginal cord. Chambers 1.4x higher then long in B-form. Proloculus in microspheric form is about 0.020mm whilst in megalospheric form is 0.19mm in diameter.

***Dimensions***: in mm. Megalospheric form in axial section 3.4mm in diameter and 0.9mm thick. Microspheric form in equatorial section 1.9mm in diameter.

**A-form**: axial section

| Whorl | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Radius ( mm) | 0.27 | 0.47 | 0.58 | 0.75 | 0.88 |

**B-form**: equatorial section

| Whorl | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Radius(mm) | 0.19 | 0.28 | 0.45 | 0.61 | 0.78 | 1.01 |
| Chambers | 8 | 12 | 14 | 16 | 19 | 29 |

***Remarks***: The present specimen shows some similarities with those described by Hanzawa (1964). However, the former is more tightly coiled, slightly larger in test size and has a larger proloculus.

***Geographical distribution and stratigraphical range:*** Previously unknown from Oman. Originally described from the Akashimisaki Formation, Lower Eocene (Ypresian) of Japan (Hanzawa 1964).

***Local range and faunal associations***: Found in the Wadi Musawa Section SE Oman in association with *N. globulus* indicating an Early Eocene (Ypresian) age. *N. globulus* is considered by Schaub (1981) to be a zonal species for the Middle Ypresian.

***Nummulites maculatus*** **Nuttall, 1926**

Pl. 20, Figs. 2-3

***Synonymy***: *Nummulites maculatus* Nuttall SAMANTA 1981, p. 15, Pl. 1, figs 1-2; Pl. 2, Fig. 2; Pl. 3, Figs. 5-6, Pl. 4, 1-3. *cum syn.*

***Material***: Four specimens in random thin section from sample WME 190.

***Diagnosis***: A-form: Small inflated lenticular test with sharp periphery. The proloculus in axial section is remarkably large (0.4-0.5mm). Thin wavy pillars occur from the centre to the periphery of the test. There are approximately three whorls in a radius of 2.1mm.

***Dimensions***: in mm. Two axial sections of A-form measured.

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 2.90 | 2.40 | 2.65 |
| Height | 1.22 | 1.05 | 1.13 |
| H/D | 0.42 | 0.43 | 0.42 |

***Remarks***: Oman specimens of *Nummulites maculatus* are all A-forms and resemble those described from India by Samanta (1981; Pl. 1, Figs. 1-5). Racey (1995; Pl. 6, figs 10, 12) found only B-forms in Oman.

***Geographical distribution and stratigraphical range***: Previously recorded from the Middle Eocene of India (Nuttall, 1926) and from upper the part of the Middle Eocene (Samanta 1981) and from Latest Lutetian to early Biarritzian of Oman (Racey 1995).

***Local range and faunal associations***: Found in Wadi Musawa in association with *Truncorotaloides topilensis*, *Truncorotaloides libyaensis*, *Morozovella bolivariana and Globigerinatheka curryi* indicating a late Middle Eocene age within the *Truncorotaloides libyaensis/Morozovella bolivariana* Zone P13, which is equivalent *to Orbulinoides beckmanni* Zone P13 of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Nummulites* cf *schaubi* Racey, 1992**

Pl. 23, Fig. 5

***Material***: A single B-form specimen (oriented axial section) from the Wadi Musawa section in sample WME 197.

***Diagnosis***: Test lenticular flattened, with sharp periphery. Pillars are very thin and concentrated around the polar area, disappearing towards the periphery. Marginal cord and spiral wall thick.

***Dimensions***: in mm

Diameter 5.0mm

Thickness 1.8mm

***Remarks***: The present specimen is similar to those described by Racey (1992b and 1995: Pl. 6, Figs. 1-7). This species differs from *N. arnii*, which was described by Schaub (1981: Pl. 47, figs 31-37) in being larger with a tighter spire and more whorls as noted by Racey (1995).

***Geographical distribution and stratigraphical range***: This species was originally described from the Middle Eocene (Lutetian) of the Seeb Limestone Formation, Wadi Rusayl, northern Oman Mountains by Racey (1992 and 1995).

***Local range and faunal associations***: Found in the Wadi Musawa Section SE of Oman. It occurs in sample (WME 197) in association with *Truncorotaloides topilensis, Truncorotaloides libyaensis, Globigerinatheka curryi* and *Morozovella bolivariana* indicating a (Late Lutetian) Middle Eocene age. If correctly determined this would extend the range of *N. schaubi* from basal Lutetian to Late Lutetian. This species is found within (P13-P14) *Truncorotaloides libyaensis/ Morozovella bolivariana* and *Truncorotaloides libyaensis* Zones, which are equivalent to *Orbulinoides beckmanni* and *Truncorotaloides rohri* Zones of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

***Nummulites striatus* Bruguiere, 1792**

Pl. 22, Fig. 2, Pl. 23, Figs. 1-4

***Synonymy***: [*Fide*] *Nummulites striatus* BRUGUIERE Racey 1995, p. 60-61, Pl. 1, Figs. 1-4, 10-11, *cum syn.*

***Material***: Two specimens in random thin section and three oriented sections; two axial and one equatorial, from samples WME 233 and WME 236.

***Diagnosis***: This species is characterised by its lenticular to subglobular, inflated to biconical test with a sharp periphery and distinct polar pillar. In equatorial section it has distinctive radiating to straight septa, curved towards to polar region.

***Dimensions:*** in mm 4-axial sections of A-forms and one equatorial section of a B-form measured.

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 4.30 | 3.20 | 3.75 |
| Height | 1.70 | 1.30 | 1.50 |
| H/D | 0.40 | 0.40 | 0.40 |

***Dimensions***: in mm. Equatorial of B-form.

Diameter 4.40mm Thickness 1.60

**B-form**

| Whorl | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Radius (mm) | 0.19 | 0.36 | 0.61 | 0.83 | 1.16 | 1.52 | 1.88 |
| No. Chambers | 8 | 14 | 22 | 25 | 29 | 34 | 43 |

***Remarks:*** The present specimen is similar to those described by Racey (1988 and 1995) from Jabal Hafit, northern Oman. It differs from *N. beaumonti* and *N. discorbinus* in having longer chambers, a slightly thinner marginal cord and a looser spire.

***Geographical distribution and stratigraphical range:*** Previously recorded from Italy (Dainelli 1915), Egypt (Cuvillier 1930), Algeria (Flandrin 1938), Northern Spain (Llueca 1929), Somaliland (Azzaroli 1952), Iran (Rahaghi 1978) and Oman (Racey 1988 and 1995). Ranges from uppermost Lutetian to mid Priabonian according to Schaub (1981).

***Local range and faunal associations:*** Found in the Wadi Musawa section in association with *Discocyclina javana* indicating a Late Eocene (Priabonian) age.

**Genus *Operculina* d'Orbigny 1826**

Type species *Lenticulites complanatus* Defrance, 1822

***Operculina musawaensis* sp. nov**

Pl. 18, Fig. 4, Pl. 22, Figs. 7-9

***Material:*** Twelve A-form specimens from sample WM 35, Wadi Musawa Section.

***Type species:*** Holotype: Pl. 18, Fig. 4

Paratype: Pl. 22, Figs. 7-9

***Derivation of name***: Named after Wadi Musawa, SE Oman Mountains the locality from which the species is first described.

***Diagnosis:*** A small heavily pustular species with distinctive large polar pustule and relatively few chambers per whorl with a markedly tight spire (4 whorls in a radius of about 1mm).

***Description:*** Holotype A-form: Test discoidal, flat with an inflated polar region. Marginal cord is well-developed with septal sutures radial and recurved towards the periphery. Chambers are 1.5-2x higher than long with twenty-four arcuate chambers in the last whorl. The spire is relatively tight and opens uniformly. The proloculus has a diameter of 0.035-0.043mm.

***Dimensions***: in mm.

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 1.7 | 1.6 | 1.65 |
| Height | 0.22 | 0.17 | 0.19 |
| H/D | 0.12 | 0.10 | 0.11 |

**A-form (Paratype)**

| Whorl | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Radius (mm) | 0.15-0.17 | 0.24-0.35 | 0.56-0.64 | 1.01 |
| Chambers | 7-8 | 11-16 | 17-19 | 22-25 |

***Remarks***: This species is similar to *Operculina campi* described by Graham (1950) from the Meganos Formation of California, but differs in possessing more whorls (6-7 whorls in *Operculina campi*) and a flatter, more compressed test. Moreover *Operculina campi* is only known from the Miocene. It differs from *Operculina jiwani* described by Racey from the Lower Eocene of Oman (1995; Pl. 10, Figs. 13-15) in that *Operculina jiwani* is bigger in diameter (2.37mm) and has larger proloculus (0.36mm). However, both species have a similar number of chambers.

***Geographical distribution and stratigraphic range***: Previously unknown.

***Local range and faunal associations***: Found in Wadi Musawa in the Abat Formation in association with *Acarinina aspensis*, *Acarinina esnaensis* and *A. soldadoensis* within the *Acarinina soldadoensis* Zone (P6) indicating an Early Eocene age.

**Genus *Miscellanea* Pfender, 1935**

Type species: *Nummulites miscella* d'Archiac and Haime, 1854

***Miscellanea primitiva* Rahaghi, 1983**

Pl. 19, Fig. 10, Pl. 20 , Figs. 8-9

*Synonymy*: *Miscellanea* cf *miscella* d'Archiac and Haime PFENDER 1935, text-Fig. 2.

*Miscellanea primitiva* Rahaghi 1983, p. 61-62, Pl. 42, Figs. 8-16. - White 1989, p. 326-327, Pl. 21, Figs. 15-16.

***Material***: Three specimens in random thin section from samples WMC 17 and WMC 18.

***Diagnosis:*** *Miscellanea primitiva* is characterised by unequally biconical test, with large pillars extending from the center of both sides which give the surface an irregular rugosity.

***Dimensions***: in mm.

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 1.8 | 1.6 | 1.70 |
| Height | 0.9 | 0.8 | 0.85 |
| H/D | 0.5 | 0.5 | 0.50 |

***Remarks***: This species differs from *Miscellanea multicolumnata* in having a smaller proloculus 0.09mm versus 0.12mm in *M. multicolmnata* and in having distinctive central pillars. The Oman specimen closely resembles *M. primitiva* described by Rahaghi (1983) and differs from *Miscellanea iranica* in having a larger test.

***Geographical distribution and stratigraphical range***: Iran (Rahaghi 1983) and Oman (White 1989) where this species was recorded within the Late Palaeocene *Alveolina primaeva* zone.

***Local range and faunal association***: Found in the Wadi Musawa Section SE of Oman in association with *Daviesina iranica* also considered to be Late Palaeocene (Thanetian) in age.

**Genus *Daviesina* Smout, 1954**

Type species: *Daviesina khatiyahi* Smout, 1954

***Daviesina iranica* Rahaghi, 1983**

Pl. 20, Figs.5-6

*Synonymy*: *Daviesina iranica* Rahaghi 1983: p.60, Pl. 41, Figs. 1-18. – White 1989: p. 290, Pl.19, Fig. 1.

*Material*: Two specimens found in random thin section in samples WM 11 and WMC 16.

***Diagnosis***: *Daviesina iranica* is characterised by its strongly compressed and operculine test and poorly ornamented spiral surface and by its convex ventral side. The periphery of the test is subacute.

***Dimensions***: in mm two axial sections measured.

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 2.4 | 2.1 | 2.25 |
| Height | 0.97 | 0.80 | 0.88 |
| H/D | 0.40 | 0.38 | 0.39 |

***Remarks***: The present specimens from Wadi Musawa section closely resemble those described by Rahaghi (1983). The species differs from *Daviesina khatiyahi* in having distinct pillars at the centre of the test.

***Geographical distribution and stratigraphical range***: Iran (Rahaghi 1983), Oman (White 1989) and China (Wan Xiaoqiao 1987).

***Local range and faunal associations***: *Daviesina iranica* was originally described from the Late Palaeocene of Iran by Rahaghi (1983) and from Oman by White (1989) from the Late Palaeocene *Alveolina primaeva* Zone. In the present study it occurs in association with *D. shirazensis* and is considered to be Late Palaeocene in age.

## ***Daviesina shirazensis* Rahaghi, 1983**

Pl. 20, Fig. 7

***Synonymy***: *Daviesina shirazensis* Rahaghi 1983, no. 10, p. 59.

***Material***: Two specimens in random thin section from sample WM 9.

***Diagnosis***: *Daviesina shirazensis* is characterised by a calcareous, perforate and radiate test, which is trochospiral and slightly unequally biconvex and by its rugose surface.

***Dimensions***: in mm two specimens measured.

| | |
|---|---|
| Diameter | 1.10 |
| Height | 0.70 |
| H/D | 0.64 |

***Remarks***: The Oman specimens agree with those described by Rahaghi (1983) from Iran. The species shows some similarities with *Daviesina persica* except that *Daviesina shirazensis* has more pillars at the centre and is slightly smaller in size.

***Geographical distribution and stratigraphical range***: Previously unknown from Oman. Originally described from the Palaeocene of Iran (Rahaghi 1983).

***Local range and faunal association***: *Daviesina shirazensis* was found at Wadi Musawa in association with *Daviesina iranica* and is considered to be of Late Palaeocene age (Thanetian) within *Morozovella acuta* Zone P4, which is equivalent to the *Planorotalites pseudomenardii* Zone P4 of Blow (1969; 1979) and Berggren *et al.* (1988).

### Family **LINDERINIDAE Loeblich and Tappan, 1984**

**Genus *Linderina*** Schlumberger 1893

Type species: *Linderina brugesi* Schlumberger, 1893

This genus is poorly known from Arabia. The only published record from Oman is *Linderina rajasthanensis* Singh (1953) found by White (1989) from Wadi Rusayl. White synonymised all four of Singh's species (*rajasthanensis, bikanerensis, kolayatensis, kirtharensis*) under one name (*rajasthanensis*) stating that she considered the test size, and shape (globular to discoidal with central boss, depending on amount of lateral thickening) to be insignificant.

A study of previously published illustrations in the Ellis and Messina Catalogue and from my own observations, suggests that the globular forms with umbonal lamellar thickening (e.g. Pl. 18, Figs. 5, 6, Pl. 21. Fig. 5) are all megalospheric, whereas the discoidal forms (without or with very little umbonal lamellar thickening (e.g. Pl. 18, Figs. 2-3, Pl. 21, Figs. 1-4) appear to be microspheric.

Another explanation could be that the discoidal forms are juveniles. Environmental factors also could be involved.

Until more work is undertaken on this interesting and potentially useful species, I prefer to call the globular form sp. A, and the discoidal form sp. B.

***Linderina*** sp. A

Pl. 18, Figs. 2-3, Pl. 21, Fig. 1-4

***Material***: Fourteen specimens from WME 181 and WME 183 from the Wadi Musawa section.

***Description***: Test small, biconvex, globular, stout with rounded periphery. The protoconch is circular in outline while the deteroconch is crescentic. Chambers in axial section are higher and increase gradually in thickness from the center towards the periphery. Wall finely perforated.

***Dimensions***: in mm two specimens measured one axial section and one equatorial.

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 1.40 | 1.02 | 1.21 |
| Height | 0.81 | 0.49 | 0.65 |
| H/D | 0.58 | 0.48 | 0.53 |

***Remarks***: This species differs from *Linderina bikanerensis* Singh (1953) in its large globular test and circular protoconch, and thus can be distinguished externally and internally.

***Geographical distribution and stratigraphical range***: Previously unknown from Oman.

***Local range and faunal associations***: *Linderina* sp. A is found at Wadi Musawa in association with *Globigerinatheka barri* in strata of presumed Middle Eocene age, within *Truncorotaloides topilensis* Zone P11 and *Globigerinatheka barri* Zone, which is equivalent to the *Globigerinatheka subconglobata subconglobata* and *Morozovella lehneri* Zones (P11-P12) of Blow (1969; 1979) and Berggren *et al.* (1988).

## ***Linderina* sp. B.**

Pl. 18, Figs. 5-6, Pl. 21, Fig. 5

*Material*: Twenty-five specimens from sample WME 182.

*Description*: Test large, discoidal with rim encircling the central area and with a slightly wavy periphery. Equatorial chambers arcuate, large and arranged overlapping alternately, increasing in size towards the center varying in size from 0.09mm to 0.12mm across. In axial section the test is thick at the centre and narrows towards the margins. Pillars fine, radial over most of the test. Protoconch in axial section is about 0.11mm, whilst in equatorial section it is 0.08mm in diameter.

*Dimensions*: in mm

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 2.2 | 1.5 | 1.85 |
| Height | 0.33 | 0.29 | 0.31 |
| H/D | 0.15 | 0.19 | 0.16 |

*Remarks*: This species is characterised by its discoidal test, wavy periphery and distinctive equatorial chambers.

*Geographical distribution and stratigraphical range*: Previously unknown.

***Local range and faunal associations***: *Linderina* sp. B is found in Wadi Musawa in association with, *Truncorotaloides topilensis and Morozovella* sp. D indicating a Middle Eocene age within the *Truncorotaloides topilensis* Zone P11, which is equivalent to the *Globigerinatheka subconglobata subconglobata* Zone P11 of Blow (1969; 1979) and Berggren *et al.* (1988).

**Family ASTEROCYCLINIDAE Bronnimann ,1951**

**Genus *Asterocyclina* Gumbel, 1868**

***Asterocyclina* sp. A**

Pl. 20, Fig. 10

***Material***: Three specimens in random thin section WMC 16.

***Description***: Test large and moderately compressed with thin peripheral zone. The embryonic apparatus is large (about 0.11mm) and rounded. The equatorial chambers are large, low near the center and higher towards the periphery, whilst lateral chambers are arranged in regular tiers. Pillars are fine and occur towards the margins of the test.

***Dimensions***: two specimens were measured.

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 2.90 | 2.8 | 2.85 |
| Height | 0.75 | 0.66 | 0.70 |
| H/D | 0.26 | 0.23 | 0.24 |

***Remarks***: The species is similar to *Asterocyclina alticostata* described from the Middle Eocene (Lutetian) of India by Lahiri (1981) but differs in having larger embryonic chambers 0.11mm to 0.14mm as opposed to 0.10mm in *A. alticostata.*

***Geographical distribution and stratigraphical range***: Previously unknown.

***Local range and faunal associations***: This species is found in Wadi Musawa in association with *Daviesina iranica* indicating a Late Palaeocene age.

***Asterocyclina* sp. B**

Pl. 18, Fig.1, Pl. 19, Fig. 5

***Material***: Two specimens were studied from sample WM 35.

***Description***: A-form equatorial section: Test is medium size, compressed with a slightly elevated umbo surrounded by a wide flange and is stellate in outline. There are 5-7 prominent rays, which narrow towards the embryon and broaden towards the periphery. In equatorial section the proloculus is very small (not measurable) and is followed by planispirally arranged arcuate nepionic chambers. Chambers are rectangular arranged in annuli and are stellate in outline and are elongate along the rays.

***Dimensions***: in mm

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 1.70 | 1.01 | 1.35 |
| Height | 1.20 | 0.12 | 0.65 |
| H/D | 0.70 | 0.11 | 0.40 |

***Remarks***: The present specimen differs distinctly from *Astreocyclina taramellii* Munier-Chalmas (1891) in the shape and size of the test and in the number and characters of the rays. The present species resembles the Indian species *Asterocyclina alticostata* which was recorded by Lahiri (1985) but differs in having slightly larger embryonic.

***Geographical distribution and stratigraphical range***: Previously unknown.

***Local range and faunal associations***: Found in Wadi Musawa in association with *Acarinina soldadoensis* and *Acarinina esnaensis* indicating an Early Eocene age within the *Acarinina soldadoensis* Zone P6, which is equivalent to *Morozovella subbotinae* Zone P6 of Blow (1969; 1979) and Berggren *et al.* (1988).

**Family DISCOCYCLINIDAE Galloway, 1928**

**Genus *Discocyclina* Gumbel, 1870**

Type species: *Orbitolites pratti* Michelin, 1846

***Discocyclina* sp. cf. *D. dispansa* Sowerby, 1840**

Pl. 19, Fig. 11

***Material***: Two specimens found in random thin sections from sample WME 190, both are axial sections.

***Diagnosis***: Test moderately large sized, biconvex, inflated and curved. The embryon is large (about 0.5mm) and of semi-nephrolepine type. The equatorial chambers are thicker towards the edges.

***Dimensions***: in mm

| | |
|---|---|
| Diameter | 4.80 |
| Height | 2.70 |
| H/D | 0.56 |

***Remarks***: This species resembles *D. dispansa* described by Samanta (1985), but has a thicker and more curved test. It is characterized by a well developed central boss which is surrounded by thin flange.

***Geographical distribution and stratigraphical range***: India (Nuttall, 1926; Samanta 1965) and Pakistan (White, 1989) from the Middle Eocene *Nummulites gratus* zone.

***Local range and faunal associations***: Found in Wadi Musawa in association with *Nummulites maculatus* indicating a Middle Eocene age within the *Truncorotaloides libyaensis* Zone (P14), which is equivalent to the *Truncorotaloides rohri* Zone (P14) of Blow (1969; 1979) and Berggren *et al.* (1988).

**_Discocyclina_ sp. aff. _D. javana_ Verbeek, 1892**

Pl. 19, Fig. 9

***Material***: Three specimens in axial section found in random thin sections in sample WME 190.

***Dimensions***: in mm. Axial section A-form 2.8mm diameter and 0.6mm thickness.

***Remarks***: This species resembles *D. javana* but is bigger in size with thicker equatorial chambers towards the periphery.

***Geographical distribution and stratigraphical range***: Indonesia (Verbeek and Fennema, 1896), India (Samanta, 1964). Recorded from the Late Eocene of India by Samanta (1985).

***Local range and faunal associations***: Found in Wadi Musawa in association with *Nummulites striatus* indicating a Late Eocene age within the *Truncorotaloides libyaensis* Zone (P14), which is equivalent to *Truncorotaloides rohri* Zone (P14) of Blow (1969; 1979) and Berggren *et al.* (1988).

**Family LEPIDOCYCLINIDAE Scheffen, 1932**

**Subfamily LEPIDOCYCLININAE Scheffen, 1932**

**Genus _Lepidocyclina_ Gumbel, 1870**

Type species: *Nummulites mantelli* Morton, 1833

**_Lepidocyclina_ (_Nephrolepidina_) sp.**

Pl. 21, Figs. 6-7

***Material***: Twelve specimens found in sample WS 97 from the Wadi Suq Section.

***Description***: A-form.

Test lenticular, usually circular but occasionally stellate in outline, with pillars over entire test surface. In equatorial section the equatorial chambers are relatively medium in size and diamond shaped, with distinct lateral chambers in axial section. The equatorial chamber layer becomes distinctly thicker towards the periphery.

B-form not found.

***Dimensions***: A-form in axial section diameter 1.6mm and 0.8mm thickness.

***Remarks***: The present specimens are characterised by their small size, inflated biconvex test, rather small embryonic apparatus (nephrolepidine) and open lateral chambers which suggest it should be assigned provisionally to the genus *Nephrolepidina*. This form differs distinctly from *Eulepidina dilatata*.

***Geographical distribution and stratigraphical range***: Unknown previously from Oman.

***Local range and faunal associations***: Found in Wadi Suq in association with *Nummulites fichteli* indicating a probable mid Oligocene age.

### ***Lepidocyclina (Eulepidina)* sp.**

Pl. 19, Fig. 7

***Material***: Four specimens in random thin section, Wadi Suq WS 106.

***Description***: Test is large compressed lenticular with raised umbo. Test wall thickest at the centre and thinning towards the periphery. In axial section the embryonic apparatus is large (1.2mm in diameter), eulepidine in shape. There are 8 to 12 rectangular lateral chambers with concave walls towards the margins.

***Dimensions***: in mm figured specimen measured.

| | |
|---|---|
| Diameter | 4.20 |
| Height | 1.20 |
| H/D | 0.28 |

***Remarks***: This specimen is characterised by its large test, with raised umbonal region and eulepidine embryonic apparatus. The species differs from *L.* (*Eulepidina*) *dilatata* described by Nuttall (1925) in having a larger test size and larger proloculus. However, inadequate material is present to allow a more detailed examination.

***Geographical distribution and stratigraphical range***: Unknown previously from Oman.

***Local range and faunal associations***: Found in Wadi Suq in association with *Nummulites fichteli* indicating a mid-Oligocene age.

**Superfamily ORBITOLINACEA Martin, 1890**
**Family ORBITOLINIDAE Martin, 1890**
**Subfamily DICTYOCONINAE Moullade, 1965**
**Genus *Dictyoconus* Blackenhorn, 1900**
Type Species: *Patella egyptiensis* Chapman, 1900
***Dictyoconus egyptiensis* (Chapman, 1900)**
Pl. 22 Figs. 10-11

***Synonymy***: *Dictyoconus egyptiensis* Chapman - WHITE 1989, p. 181-184, Pl. 8, Figs. 6-8. *cum syn.*

***Material***: Six specimens from sample WME 98, Wadi Musawa section.

***Diagnosis***: This species has a distinctive high conical shape. Early chambers are planispiral, later chambers rectilinear or dish-shaped and divided into a central shield separated by a marginal ridge from a marginal trough.

***Dimensions***: in mm.
Height 1.7
Width 1.5

***Remarks***: This species compares closely with those illustrated and described by White (1989) from Wadi Bani Khalid to the North of the present studied area. (see White 1989 for description).

***Geographical distribution and stratigraphical range***: Previously recorded from the Early to Middle Eocene of Egypt, Iraq, Iran, Somalia, Pakistan and India. White (1989) recorded the species from the Early Eocene of Oman.

***Local range and faunal association***: *Dictyoconus egyptiensis* was found in the Wadi Musawa section in association with *Morozovella caucasica* and *M. aequa* indicating an Early Eocene age within the *Morozovella marginodentata* Zone (P8), Which is equivalent to *Morozovella aragonensis* Zone (P8) of Blow (1969; 1979) and Berggren *et al.* (1988).

**_Coskinolina balsilliei_ Davies, 1930**

Pl. 22, Fig. 12

***Synonymy***: *Coskinolina balsilliei* Davies 1930b: p. 496, Pl. 1, Figs. 6-9, Pl. 2, Figs. 4-6, 15.

***Material***: Eight specimens from sample WME 111.

***Diagnosis***: Characterised by its conical test with a slightly convex base and by its planispiral early chambers and rectilinear later chambers.

***Dimension***: in mm

| | |
|---|---|
| Diameter | 2.17 |
| Height | 1.70 |
| H/D | 0.78 |

***Remarks***: The present specimens are similar to those described by Davies (1930b), from Northern Baluchistan. This species differs from *Coskinolina cookei* Moberg

(1928, p.166, Pl. 3, Figs. 1-8, Pl. 5, Fig. 3) which has a slightly concave base rather than a convex one as in *C. balsilliei*.

***Geographical distribution and stratigraphical range***: Previously unknown from Oman. Recorded from Baluchistan by Davies (1930b).

***Local range and faunal association***: Found in Wadi Musawa in association with *Morozovella crater* indicating an Early Eocene age. This species is found within the *Morozovella caucasica Zone* (P9) age, which is equivalent to *Acarinina pentacamerata* Zone (P9) of Blow (1969; 1979) and Berggren *et al.* (1988).

**Family ALVEOLINIDAE Ehrenberg 1839**

**Genus *Alveolina* d'Orbigny, 1826**

***Alveolina katicae* White, 1992.**

Pl. 19, Fig. 4

***Synonymy***: *Alveolina (Alveolina) katicae* White 1992: p. 68, Pl. 3, Figs. 4-7.

***Material:*** Two specimens from sample WM 34, in the Wadi Musawa section, only the megalospheric-oriented specimen is illustrated here.

***Diagnosis***: This species is characterised by its small subcylindrical to fusiform test and kidney-shaped proloculus which has a diameter of 0.17 mm.

***Dimensions:*** in mm

| | |
|---|---|
| Diameter | 2.38 |
| Height | 0.70 |
| H/D | 0.30 |

***Remarks:*** The Oman specimens compare well with those described by White (1992) but only occur in the lower part of the Early Eocene whilst White's ranged from Lower to Middle (*Alveolina stipes* zone) Eocene. The illustrated specimen also shows similarities with *Alveolina vredenburgi*, described by Davies (1937) from the Punjab

Salt Range of India, in its external features. However, Davies did not illustrate any oriented sections for suitable comparison. The Oman specimen is therefore questionably assigned to *Alveolina katicae*.

***Geographical distribution and stratigraphical range:*** Previously known only from Oman (White, 1992) with a range from late Early to early Middle Eocene (*Alveolina stipes* Zone).

***Local range and faunal association:*** *Alveolina katicae* is found in Wadi Musawa in association with *Acarinina soldadoensis* and *A. esnaensis* indicating an Early Eocene age.

**Family ACERVULINIDAE Schultze, 1852**

**Genus *Gypsina* Carter, 1877**

Type species: *Polytrema planum* Carter, 1876

***Gypsina globulus* (Reuss, 1848)**

Pl. 22, Fig. 6

***Synonymy:*** [*Fide*] *Gypsina globulus* (Reuss)- WHITE 1989, p.280-282, Pl. 18, Figs. 6-7 *cum syn.*

***Material***: Ten specimens from sample WME183, Wadi Musawa section.

***Diagnosis***: This species is characterised by its spherical test and arcuate chambers arranged in concentric rows and by its coarse perforation.

***Dimensions***: in mm

Diameter 1.1

***Remarks***: Pseudo-pillar like structures occur between the rows of chambers producing well developed low protruberances on the test surface. Present specimens resemble those illustrated by White (1989) from Wadi Amq Northern Oman.

***Geographical distribution and stratigraphical range***: Recorded from India (Samanta, 1983 and Lahiri, 1985) and Oman (White, 1989).

***Local range and faunal associations***: *Gypsina globulus* is found in Wadi Musawa in association with *Truncorotaloides libyaensis* and *Globigerinatheka barri* indicating a Middle Eocene age within the *Globigerinatheka barri* Zone (P12), which is equivalent to *Morozovella lehneri* Zone (P12) of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

*Gypsina* sp.

Pl. 22, Fig. 3

***Material***: Five specimens from samples WME 227 and WME228.

***Description***: Test spherical, calcareous and perforate. Chambers are arcuate or truncate. The truncate chambers are distinct, large and connected by a fine row of perforations.

***Dimensions***: in mm

Diameter 1.33

***Remarks***: This species differs from those described by White (1989: p. 280-282, Pl.18, Figs. 6-7) in its distinct truncate chambers and well-developed row of pores (stolons) between the chambers.

***Geographical distribution and stratigraphical range***: Previously unknown from Oman.

***Local range and faunal associations***: Found in Wadi Musawa in association with *Nummulites striatus* indicating a lower Late Eocene age.

**Family ROTALIIDAE** Ehrenberg, 1839

Type species: *Neorotalia mexicana* (Nuttall) 1928

***Neorotalia omanensis* sp. nov.**

Pl. 18, Figs. 7-12, Pl. 19, Fig. 6, Pl. 22, Figs. 4-5

***Material***: Twenty-three specimens found in samples WME 148 (Unit G) and WME 184 (Unit H), from the Musawa Formation, Wadi Musawa Section, SE Oman.

***Type- specimens***: Holotype Pl. 18, Figs.10-12, sample WME184.
Paratype Pl. 18, Figs. 7-9, sample WME148.

***Derivation of name***: Named after Oman the country from which the species is first described.

***Diagnosis***: A distinctive large (0.8mm diameter) planoconvex species of *Neorotalia* with about 9-13 chambers in the last whorl. Surface coarse and pustulate, umbilical region characterised by a rosate pattern of plugs.

***Description***: Test trochoid, rounded planoconvex. Periphery lobate to subcircular. There are about 3-3.5 whorls with 9-13 triangular chambers in the last whorl. Umbilical side strongly convex with large pillars on the umbilical shoulder surrounded by fine pustules. Spiral side flat to slightly convex with pustules coarser towards centre. Aperture is extraumbilical-umbilical.

***Dimensions***: Holotype Diameter 0.8mm. Thickness 0.3mm
Paratype Diameter 0.6mm. Thickness 0.2mm

Paratypes dimensions in mm.

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 0.70 | 0.55 | 0.58 |
| Height | 0.35 | 0.25 | 0.30 |
| H/D | 0.46 | 0.45 | 0.45 |

***Remarks***: Omani specimens are slightly different from *Neorotalia aticantina* described by Colom (1954) whose specimens were biconvex and smaller in size (0.4 to 0.6mm in diameter). The genus shows some similarities with *Daviesina* species in shape though *Daviesina* differs in having a circular to subcircular, slightly trochospiral test with large pillars on umbilical shoulders.

***Geographical distribution and stratigraphical range***: The genus is previously unknown from Oman and the Middle East.

***Local range and faunal associations***: Found in the Musawa Formation in association with *Truncorotaloides topilensis, Morozovella edgari* and *Globigerinatheka euganea* indicating a lower to middle Lutetian age. This species ranges from the *Truncorotaloides topilensis/Morozovella edgari* Zone (P10) to the *Globigerinatheka barri* (P12), which is equivalent to the *Hantkenina nuttalli* Zone (P10) to *Morozovella lehneri* Zone (P12) of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

**Incertae sedis**

Pl. 21, Figs. 8-9, Pl. 23, Figs. 6-8

***Material***: Forty-six specimens from sample WME 148, Wadi Musawa.

***Description***: External: Test cone shape with circular to slightly convex base. There are 14-18 triangular chambers arranged alternatively and divided by thick sutures or septa. The aperture is rounded and surrounded by a thick lip located at the top of the cone.

Axial section: Small sized glassy tube-like narrowing towards the top and infilled with calcite. Periphery round slightly lobate. Sutures are straight. Aperture rounded raised and surrounded with two lips.

Equatorial section: Rounded plate-like shape, divided into four triangular chambers. Periphery rounded with a thick margin.

***Dimensions***: in mm. Six specimens measured, figured and illustrated.

| | Maximum | Minimum | Average |
|---|---|---|---|
| Diameter | 0.80 | 0.40 | 0.60 |
| Height | 0.40 | 0.20 | 0.30 |
| H/D | 0.50 | 0.50 | 0.50 |

***Remarks***: This interesting microfossil has some similarity to *Bolboforma* but the Omani specimens were difficult to equate with that enigmatic organism because of their conical shape, spherical outline and atypical ornament; furthermore, the interior is subdivided unlike *Bolboforma* (see Pl. 21, Figs. .8, 9).

***Geographical range and stratigraphical range***: Unknown previously.

***Local range and faunal associations***: Found in Wadi Musawa in association with *Truncorotaloides topilensis, Globigerinatheka euganea* and *Turborotalia blowcentralis* nom. nov. indicating a Middle Eocene (Lutetian) age within the *Truncorotaloides topilensis/Morozovella edgari* Zone (P10), which is equivalent to the *Hantkenina nuttalli* Zone (P10) of Blow (1969; 1979) and Berggren *et al.* (1988) respectively.

# *Chapter Six*
# *Biostratigraphy*

# Chapter Six
## BIOSTRATIGRAPHY

### 6.1 INTRODUCTION

A biostratigraphic zonation for the Upper Palaeocene-Eocene of the Wadi Musawa section has been established based largely on planktonic Foraminifera and to a lesser extent larger Foraminifera (Fig. 6.1). This study of the planktonic foraminiferal zones of the Wadi Musawa Section includes a discussion of differing interpretations of the various zone boundaries and stages of the Palaeogene based mainly on the more important index species (Fig. 6.2).

There are significant gaps in the Wadi Musawa section where there is either no exposure or where the sediments exposed have not yielded age diagnostic microfossils. These intervals of uncertainty have been marked on the summary log on the measured section as "unzoned" (see enclosure Fig. 3.2). Consequently although zones P4 and P5 and P8 to P14 are identified it is possible that there are significant breaks in the sequence within or between these zones.

The planktonic Foraminifera occur only at certain horizons (see Fig. 6.3) and there is a general lack of nominate zonal index species (of Blow, 1969, 1979). However, the associations present (with overlaps and acmes) do allow the recognition of most of the world wide P zones of the international scale despite the present of the numerous gaps and breaks in sedimentation i.e. local expression of the standard zones.

The Foraminifera species characterising each zone are the same as those described in many parts of the world; in Mexico by Blow (1969), in the western hemisphere by Bolli (1957), Loeblich and Tappan (1957), Berggren (1965) and Hay (1960); in Egypt by El-Naggar (1966); in the Soviet Union by Subbotina (1953; 1960); in New Zealand by Jenkins (1960, 1966); and in the Arabian Peninsula by Page (1959), El-Khayal (1969) and Hasson (1985).

## 6.2 MAASTRICHTIAN

The Upper Maastrichtian is not well developed in the study section, although there are obvious elements of a Late Cretaceous fauna reworked into the Upper Palaeocene. The K/T boundary is not included herein as it requires further field work and collection/analysis of additional samples through the excavation of a trench across this unexposed (scree covered) interval. However, several planktonic foraminiferal species from the Maastrichtian are figured herein (determined by Lynne McCarthy) including *Heterohelix labellosa* (Pl. 17, Fig. 7), *Rugoglobigerina rugosa* (Pl. 17, Fig. 10), *Trinitella scotti* (Pl. 17, Fig. 8), *Planohedbergella voluta* (Pl. 17, Fig. 11), *Globotruncana mariei* (Pl. 17, Fig. 9) and *Globotruncana rosetta* (Pl. 17, Fig. 12).

## 6.3 PALAEOCENE TO EOCENE

The Upper Palaeocene and the Lower to Middle Eocene succession comprises the Abat and Musawa Formations. A biostratigraphical zonation based on planktonic Foraminifera was established for the Lower Tertiary in the Wadi Musawa section in order to create a framework for later correlation with adjacent regions e.g United Arab Emirates, Saudi Arabia etc (Fig. 6.4). This represents the first detailed planktonic foraminiferal study yet carried out on the Tertiary of Oman.

Forty-one planktonic Foraminifera species are identified and described in Chapter 4. Only three of Blow's (1969, 1979) zones could be recognised on the occurrence of their nominate species (these are zones P5, P8 and P9). For this reason it was desirable to erect a local zonation, using the known ranges those species. The known stratigraphic distribution of these species was used to recognise the zones P5, P8-P9 as equivalent to standard zones of Blow, 1969, 1979, while strata considered generally equivalent to P4 and P10-P14 in the Wadi Musawa section are zoned on the basis of the local range (Fig. 6.3).

The Lower and Middle Palaeocene zones are missing in the studied section (P1-P3) as is common throughout most of the Arabian Peninsula and Gulf (Jones and Racey, 1995). In this study the missing zones P6 and P7 (Lower Eocene) suggest there is an hiatus, possibly due to local tectonic activity in the Wadi Musawa area. It is not known for certain the exact extent of this hiatus i.e where the whole of P6 and P7 are missing, but evidence from the western Oman Mountains on the Batinah Coast between the Lower and Upper Jafnayn Formation members (Racey 1995 and Al-Sayigh and Racey in prep.) as shown in Fig. 2.9 suggests that this is indeed the case.

The Palaeocene and Eocene zones identified in the study area correspond to those defined by Blow (1969; 1979) and Berggren *et al.* (1988)) and correlate in part with those of El-Khayal (1974) and Hasson (1985) for Saudi Arabia and Anan and Hamadan (1993) for the United Arab Emirates (Fig. 6.4). The zone boundaries are determined using standard index forms for the Palaeocene and Eocene defined in Blow (1969) and Toumarkine and Luterbacher (1985).

The planktonic Foraminifera zones are defined as follows (from bottom to top):

## 6.4 UPPER PALAEOCENE

Two zones are recognised in the Upper Palaeocene of the Abat Formation in the Wadi Musawa section (Fig. 6.4). The base of the Upper Palaeocene is characterized by the first occurrence of morozovellids, which have angular-conical chambers and a well-developed keel. The two planktonic zones identified comprise the top of the *Morozovella acuta* zone (P4) of the local expression of the standard zone and the *Morozovella velascoensis* zone (P5) equivalent of the standard zone. However, the base of the Abat formation (Upper Palaeocene) unconformably overlies the Maastrichtian Simsima Formation whilst the top is unconformably overlain by the Lower Eocene Musawa formation.

### 6.4.1 *Morozovella acuta* Zone (=P4 of Blow, 1969, 1979 and Berggren *et al.*, 1988)

Partial range zone from FAD of *Morozovella nicoli* to LAD of *Subbotina triloculinoides*. This zone is considered generally equivalent to the *Planorotalites pseudomenardii* zone (P4) of the standard zonation and in the present study section is zoned on the basis of the local range. The standard *Planorotalites pseudomenardii* zone was defined by Bolli (1957a) as a total range zone, and this definition has been subsequently followed by most authors (Berggren 1969; Hardenbol and Berggren 1978; Toumarkine and Luterbacher 1985).

However, this zone is represented by samples WM1 and WM7 from the lower part of the Abat Formation. Underlying this zone is an interval of the Cretaceous. The upper limit of this zone is also marked by the last occurrence of *Morozovella angulata* (Fig. 6.3).

In addition to the zonal marker *Morozovella acuta, Morozovella angulata, Morozovella nicoli, Morozovella pusilla mediteranica* and *Subbotina triloculinoides* are present throughout the zone. This zone corresponds to the middle part of the Upper Palaeocene. Associated larger Foraminifera within this zone include *Daviesina iranica, Daviesina shirazensis* and *Miscellanea primitiva* (Fig. 6.5 and Fig. 6.6). Other benthic Foraminifera include *Nodosaria* sp., *Glandulina* sp., *Anomalinoides* sp., *Cibicides* sp. plus smaller rotaliids and textulariids.

### 6.4.2 *Morozovella velascoensis* Zone (=P5 of Blow, 1969, 1979 and Berggren *et al.*, 1988)

Partial range zone of nominate taxon between the FAD of *Morozovella occlusa* and the LAD of *Morozovella acuta*. The base of this zone is represented by sample WM22 from the Abat Formation. The lower limit of this zone is marked by first appearance of *Morozovella occlusa,* while the upper limit is also marked by last occurrence of *Morozovella velascoensis* (Fig. 6.3). This zone is characterised by the occurrence of *Morozovella velascoensis, Morozovella acuta, Morozovella occlusa* and *Morozovella* sp. cf *parva*. This zone corresponds to the uppermost Upper Palaeocene. Larger Foraminifera found within this zone include *Nummulites* sp., *Alveolina* sp. plus *Lenticulina* sp., *Nodosaria* sp., *Glandulina* sp., *Clavulina* sp. Ostracoda also occur in this zone.

## 6.5 LOWER EOCENE

Two zones were recognised in the Lower Eocene of the Abat and Musawa formations in the Wadi Musawa section. (Fig. 6.4). As previously mentioned, most if not all of P6 and P7 is missing. The recognised zones are as follows:

### 6.5.1 *Morozovella aragonensis* Zone (=P8 of Blow, 1969, 1979 and Berggren *et al.*, 1988)

Partial range zone of the nominate taxon between the FAD of *Acarinina soldadoensis* and LAD of *Morozovella marginodentata*. This zone is represented by samples WM35, WME76, WME86 and WME93 from the upper part of the Abat Formation and the lower part of the Musawa Formation. Other species recorded in this zone include *Acarinina aspensis, A. esnaensis, A. soldadoensis, Acarinina* sp. and *Morozovella aragonensis*. The lower boundary of this zone is above the extinction of *Morozovella velascoensis*, whilst the upper boundary is marked by last occurrence of *Morozovella aragonensis* and corresponds to the Lower Eocene (Fig. 6.3). This zone is also characterized by *Acarinina aspensis, Acarinina esnaensis, Acarinina soldadoensis, Morozovella abundocamerata, Morozovella caucasica, Morozovella centralis, Subbotina quadrata, Subbotina triangularis, Morozovella* sp. B and *Globigerinatheka subconglobata subconglobata* and corresponds to the Lower Eocene (P8). The larger Foraminifera within this zone include *Nummulites atacicus, N. globulus, N. honogoensis, N. fossulata, Dictyoconus egyptiensis* (Fig 6.5 and Fig. 6.6), *Operculina musawaensis* sp. *nov.*, *Alveolina katicae and Assilina* sp., plus smaller benthic Foraminifera such as *Anomalinoides, Discorbis, Bulivina, Elphidium, Uvigerina* and miliolids. Reworked Jurassic and Cretaceous Radiolaria occur within this interval.

### 6.5.2 *Acarinina pentacamerata* Zone (=P9 of Blow, 1969, 1979 and Berggren *et al.*, 1988)

Total range zone of nominate taxon between the FAD of *Morozovella gracilis* at the base and the LAD of *Morozovella crater* at the (top), representing the uppermost Lower Eocene (P9). This zone is represented by samples WME93 to WME103 from the Musawa Formation. The lower limit of this zone is marked by the disappearance of *Morozovella aragonensis* and the upper limit is also marked by the last occurrence of *Morozovella crater* (Fig. 6.3). Other planktonic Foraminifera include *Morozovella caucasica, Morozovella aequa, Morozovella crater Morozovella subbotinae and Morozovella* sp. C (Fig. 6.5). This zone based on its planktonic foraminiferal content and stratigraphical position is tentatively correlated with the *Acarinina pentacamerata* zone of Blow (1969; 1979 and Berggren *et al.*, 1988). The smaller benthic

Foraminifera found within this zone include *Anomalinoides, Discorbis, Cibicidoides, Rotalia, Textularia, Elphidium* and miliolids found together with reworked Mesozoic Radiolaria.

### 6.6 MIDDLE EOCENE

Five zones representing the Middle Eocene were recognised as local expression (on the basis of the local range) of the standard zones, spanning the upper Musawa Formation and lower Tahwah Formation in the Wadi Musawa section. (Fig. 6.4). The zones are as follows:

#### 6.6.1 *Truncorotaloides topilensis/Morozovella edgari* Zone (=P10 of Blow, 1969, 1979 and Berggren *et al.*, 1988)

Concurrent range zone of nominates taxa between the FAD of *Truncorotaloides topilensis* and LAD of *Morozovella edgari*. This zone is represented by the samples WME147-WME148 from Musawa Formation. The lower limit is marked by the disappearance of *Morozovella crater* and the upper limit by the last occurrence of *Morozovella edgari* and *Globigerinatheka euganea* (Fig. 6.3). This zone is considered equivalent to the *Hantkenina nuttalli* zone of the standard zonation. Many other species have been recorded in this zone. They include *Morozovella edgari, Globigerinatheka euganea, Truncorotaloides topilensis* and *Turborotalia blowcentralis* nom. nov. This zone corresponds to the lowermost (Lower Lutetian) Middle Eocene (P10). None of the forms occurring in the underlying zones are represented here. The associated larger Foraminifera comprise *Nummulites discorbinus, Coskinolina balsillei, Alveolina* sp., *Neorotalia omanensis* nov. sp., *Gypsina* sp., *Linderina* sp. A (Fig. 6.5 and Fig. 6.6), *Operculina* sp., *Pararotalia* and *Discocyclina* sp. plus *Textularia,* and *Nonion.*

#### 6.6.2 *Truncorotaloides topilensis* zone (=P11 of Blow, 1969, 1979 and Berggren *et al.*, 1988).

Partial range zone of the nominate taxon *Truncorotaloides topilensis*. The base of this zone is represented by the sample WME182 from Musawa the Formation. The lower boundary of this zone is marked by the disappearance of *Morozovella edgari* whilst the upper boundary is marked by the extension of *Truncorotaloides topilensis* (Fig.

6.3). This zone is characterised by *Truncorotaloides topilensis* and *Morozovella* sp. D (equivalent to the *Globigerinatheka subconglobata subconglobata* zone of the standard zonation (i.e. P11 of Blow, 1969; 1979 and Berggren *et al.*, 1988) respectively. On the basis of its planktonic foraminiferal content and the stratigraphical position, this zone is comparable to the (P11) of Blow (1969; 1979). It is regarded here as belonging to the uppermost lower part of the Middle Eocene. Larger Foraminifera occurring in this zone include *Nummulites* sp., *Operculina* sp., *Discocyclina* sp., *Gypsina* sp., plus smaller benthic Foraminifera including *Bolivina, Clavulina, Cibicides, Discorbis, Nonion, Glandulina* and miliolids.

### 6.6.3 *Globigerinatheka barri* zone (=P12 of Blow, 1969, 1979 and Berggren *et al.*, 1988).

Total range zone of the nominate taxa *Globigerinatheka barri*. The base of this zone is represented by sample WME183 from the Musawa Formation. This zone is considered equivalent to the *Morozovella lehneri* zone of the standard zonation (i.e. P12 of Blow (1969; 1979) and Berggren *et al.* (1988). The lower limit of this zone is marked by initial occurrence of *Truncorotaloides topilensis*, whilst the upper limit is marked by the last occurrence of *Globigerinatheka barri* (Fig. 6.3). Other planktonic Foraminifera occurring in this zone include *Truncorotaloides topilensis* and *Globigerinatheka* sp. A. This zone contains the larger Foraminifera *Gypsina globulus, Linderina* sp. A, *Linderina* sp. B and *Neorotalia omanensis* nov. sp. (6.5 and Fig. 6.6), plus smaller benthic Foraminifera including miliolids, *Nonion, Cibicidoides, Nonionoides, Discorbis, Clavulina, Glandulina,* and *Bulivina*. The planktonic and larger Foraminifera confirm a middle Middle Eocene age for this zone.

### 6.6.4 *Truncorotaloides libyaensis/Morozovella bolivariana* zone (=P13 of Blow, 1969, 1979 and Berggren *et al.* 1988).

Partial range zone of *Truncorotaloides libyaensis* between the FAD of *Morozovella bolivariana* and the LAD of *Truncorotaloides topilensis.* The base of this zone is represented by sample WME186 from the Musawa Formation. The other planktonic Foraminifera occurring in this zone include *Truncorotaloides topilensis, T. libyaensis, Morozovella bolivariana,* and *Globigerinatheka* sp. B. This zone is considered equivalent to the *Orbulinoides beckmanni* zone of the standard zonation P13 of Blow

(1969; 1979) and Berggren *et al.* (1988). The lower limit of this zone is marked by disappearance *Globigerinatheka barri*, and the upper limit is marked by last occurrence of *Globigerinatheka curryi* and *Truncorotaloides topilensis* (Fig. 6.3). This zone is characterized by upper Middle Eocene larger Foraminifera such as *Nummulites maculatus, Discocyclina dispansa* and *Nummulites schaubi* (Fig. 6.5 and Fig. 6.6). Other fossils commonly found in this zone include *Rotalia* sp. and reworked Mesozoic Radiolaria.

### 6.6.5 *Truncorotaloides libyaensis* zone (=P14 of Blow, 1969, 1979 and Berggren *et al.*, 1988).

Partial range zone of nominate taxon *Truncorotaloides libyaensis* above the LAD of *Globigerinatheka curryi* and *Morozovella bolivariana*. The base of this zone is represented by sample WME205 from Musawa Formation. This zone is considered equivalent to the *Truncorotaloides rohri* zone and includes only *Truncorotaloides libyaensis*. It represents the uppermost Middle Eocene (P14). The lower boundary of this zone is marked by the disappearance of *Globigerinatheka curryi* and *Morozovella bolivariana*, and the upper boundary is marked by the last occurrence of representatives of the genus *Truncorotaloides* (Fig. 6.3).

In the absence of keeled planktonic Foraminifera the youngest planktonic zones P15 and P16 of Blow (1969) are represented by the co-occurrence of *Nummulites striatus* and *Discocyclina javana* in association with *Globigerina linaperta* group unkeeled forms. The Lower to mid-Oligocene is represented by the occurrence of *Nummulites fichteli, Lepidocyclina* (*Eulepidina*) sp. and *Lepidocyclina* (*Nephrolepidina*) sp in association with representatives of the *Globigerina linaperta* group (Fig. 6.5 and Fig. 6.6).

## 6.7 DISCUSSION

In the Ja'alan area the Palaeocene-Lower Oligocene sequence comprises three formations, the Abat, Musawa and Tahwah Formations with planktonic Foraminifera generally restricted to the Abat and Musawa Formations. The planktonic foraminiferal zones recorded are mainly based on the keeled forms, which disappear at the top of the Middle Eocene. Larger Foraminifera have been used to date the Upper Eocene and

Lower Oligocene due to the apparent extinction of keeled planktonic Foraminifera and the appearance of globular forms with broad stratigraphic ranges (e.g. *Globigerina linaperta* group).

## 6.8 CORRELATION

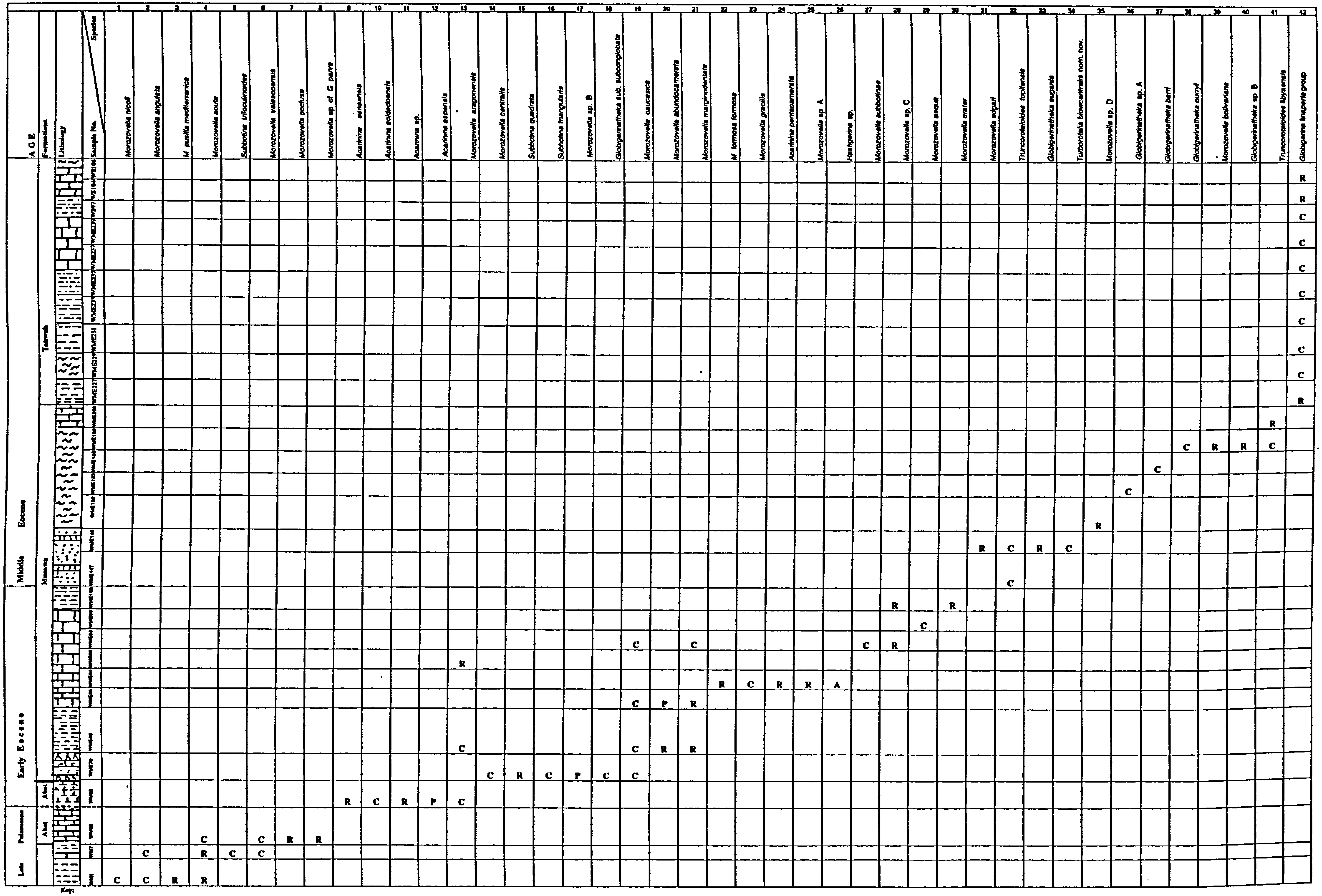
The present zones can be correlated on a regional scale with those of Anan and Hamdan (1993) from the UAE, El-Naggar (1966) from Egypt, El-Kayal (1974) and Hasson (1985) from Saudi Arabia. They also stand on par with those of Blow (1969; 1979) and Berggren *et al.* (1988). The Oman fauna allows a greater degree of subdivision using planktonic Foraminifera than has previously been possible for much of the Middle East and thus forms a reference section against which to compare other sequences from across the region (Fig. 6.4).

| Age | Formation | Sample No. / Genera | Textularia | Miliolids | Somalina | Alveolina | Nummulites | Lockhartia | Linderina | Rotalia | Assilina | Lepidocyclina | Operculina | Discocyclina | Plankton | Coskinolina | Gypsina | Neorotalia | Dictyoconus | Asterocyclina | Lenticulina | Nodosaria | Pullenia | Glandulina | Anomalinoides | Dorthia | Ammobaculites | Gaudryina | Cibicides | Bolivina |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oligocene | Tahwah | WS106 | | | | | C | | | | | R | | | C | | | | | | | | | | | | | | | |
| | | WS97 | | | | | | | | | | C | | | A | | | | | | | | | | | | | | | |
| Upper Eocene | | WME239 | | | | | | | | | | | | | R | | | | | | | | | | | | | | | |
| | | WME238 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME236 | | | | | | | | | | | | | A | | | | | | | | | | | | | | | |
| | | WME235 | | | | | | | | | | | | | C | | | | | | | | | | | | | | | |
| | | WME234 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME233 | | | | | | | | | | | | | A | | | | | | | | | | | | | | | |
| | | WME231 | | R | | | | | | | | | | | C | | | | | | | | | | | | | | | |
| | | WME230 | | A | | | | | | | | | | | P | | | | | | | | | | | | | | | |
| | | WME229 | | C | | | | | | | | | | | A | | | | | | | | | | | | | | | |
| | | WME228 | | | | | | | | | | | | | R | | R | | | | | | | | | | | | | |
| | | WME227 | | | | | | | | | | | | | | | R | | | | | | | | | | | | | |
| | | WME224 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Musawa Formation | WME215 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME214 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Middle Eocene | | WME205 | | | | | | | | | | | | | C | | | | | | | | | | | | | | | |
| | | WME200 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME199 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME197 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME195 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME194 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME193 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME192 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME190 | | A | | | r | | | | | | | a | | | | | | | | | | | | | | | | |
| | | WME186 | | | | | | | | | | | | C | A | | | | | | | | | | | | | | | |
| | | WME185 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME184 | | C | | R | | | | | | | | C | | | | C | | | | | | | | | | | A | |
| | | WME183 | | C | | C | | | C | | | | | A | A | | C | | | | | | | | | | | | | |
| | | WME182 | | A | | | | | A | | | | | | | | | | | | | | | | | | | | A | |
| | | WME153 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME150 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME148 | | | | | a | | | | | | | C | A | | | C | | | | | | | | | | | A | |
| | | WME147 | | | | P | | | | | | | | | A | | | | | | | | | | A | | | | | |
| | | WME138 | | | | | | | | | | | | | | | | | | | | | | | C | | | | | |
| | | WME124 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME123 | | R | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME116 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lower Eocene | | WME111 | | | | | | | | | | | | | | C | | | | | | | | | C | | | | | |
| | | WME109 | | c | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME106 | | C | | | | | | | | | | | R | | | | | | | | | | | | | | | |
| | | WME105 | | R | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME103 | | R | | | | | | | | | | | R | | | | | | | | | | R | | | | C | |
| | | WME102b | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME102a | | | | | | | | | | | | | | | | | | | | | | | R | | | | | |
| | | WME101 | | c | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME99 | | A | | | | | | | | | | | C | | | | | | | | | | | | | | | |
| | | WME98 | | | | | | | | | | | | R | C | | | | C | | | | | | | | | | | |
| | | WME97 | | R | | | | | | | | | | | R | | | | | | | | | | A | | | | | |
| | | WME95 | | A | | | | | | | C | | | | C | R | | | | | | | | | | | | | | C |
| | | WME94 | | A | | | p | | | | | | | | A | | | | | | | | | | | | | | | A |
| | | WME93 | | A | | | | | | | | | | | A | | | | | | | | | | | | | | | A |
| | | WME90 | | R | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WME88 | | | | | | | | | | | | | C | | | | | | | | | | | | | | | |
| | | WME86 | | r | | | | | | | C | | | | C | | | | | | | | | | P | | | | | |
| | | WME85 | | p | | | | | | | | | | | C | | | | | | | | | | | | | | | |
| | | WME76 | | r | | | | | | | | | | | A | | | | | | | | | | | | | | | |
| | | WM65b | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM65a | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM60 | | C | | | | | | | C | | | | | | | | | | | | | | | | | | | |
| | | WM58 | | c | | a | | | | | | | | | | | | | | | | | | | | | | | | |
| | Abat Formation | WM57 | | | r | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM56 | | | | a | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM55 | | c | | r | | | | | r | | | | | | | | | | | | | | | | | | | |
| | | WM54 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM53 | r | | r | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM50 | | | | | | | | | a | | | | | | | | | | | | | | | | | | | |
| | | WM49 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM48 | | | r | | | | | | | | | | | | | | | | | | | | | | | | R | |
| | | WM47b | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM47a | r | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM46 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM45 | | | | | | | | | C | | | | | | | | | | | | | | | | | | C | |
| | | WM43 | | | | | | | | | | | | | | | | | | | | | | | | | | | C | |
| | | WM42 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM41 | | | | | | | | | | | | | P | | | | | | P | | | | | | | | C | |
| | | WM40 | | | | | | | | | | | | | P | | | | | | R | | | | | | | | | |
| | | WM39 | | | | | | | | | | | | P | | | | | | | R | | | | | | | | C | |
| | | WM38 | | | | | | | | | | | | | R | | | | | | | | | | | | | | | |
| | | WM37 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM36 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM35 | | | | | A | | | | | | A | | A | | | | | C | R | | | | | | | | | |
| | | WM34 | | | | R | A | | | | | | A | | | | | | | | | | | | | | | | R | |
| | | WM32 | | | | | C | r | | | | | R | | | | | | | | | | | | | | | | | |
| | | WM31b | | | | | A | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM31a | | | | | A | | | | A | | | P | | | | | | | | | | | | | | | | |
| | | WM29 | | | | a/R | | | | | | | | | | | | | | | R | | | | | | | | | |
| Upper Palaeocene | | WM28 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM27 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM26 | | | | | | | | | | | | | | | | | | | C | P | | | | P | | R | | |
| | | WM24 | | | | P | | | | | | | | | | | | | | | A | R | | R | | | | | C | |
| | | WM22 | | | | | | | | | | | | | A | | | | | | | | | | R | | | | | |
| | | WMC21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WMC20 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WMC18 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WMC17 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WMC16 | | | | R | | | | | | | R | | | | | | | r | | | | | | | | | | |
| | | WM14 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM13 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM12 | p | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM7 | | | | | | | | | | | | | A | | | | | | C | R | | | R | C | R | | R | |
| | | WM6 | r | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM2 | p | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | WM1 | | | | | | | | | | | | | A | | | | | | C | C | R | C | C | R | | | C | |

*Lithology not to scale.*

**Fig. 6.1 Relative abundances of foraminiferal fauna in the Wadi Musawa and Wadi Suq sections.**

Upper case for picked mate: A - Abundan C - Common R - Rare P - Present
Lower case for thin section a : Abundan c: Common r: Rare P - Present




Key: P (1) R (2-5) C (5-20) Abundant (>20) (Lithology not to scale) (Samples mentioned above are only contains planktonic Foraminifera).

**Fig. 6.2 Distribution of planktonic foraminiferal species (Late Palaeocene to Early mid-Oligocene) from the Wadi Musawa and Wadi Suq sections.**

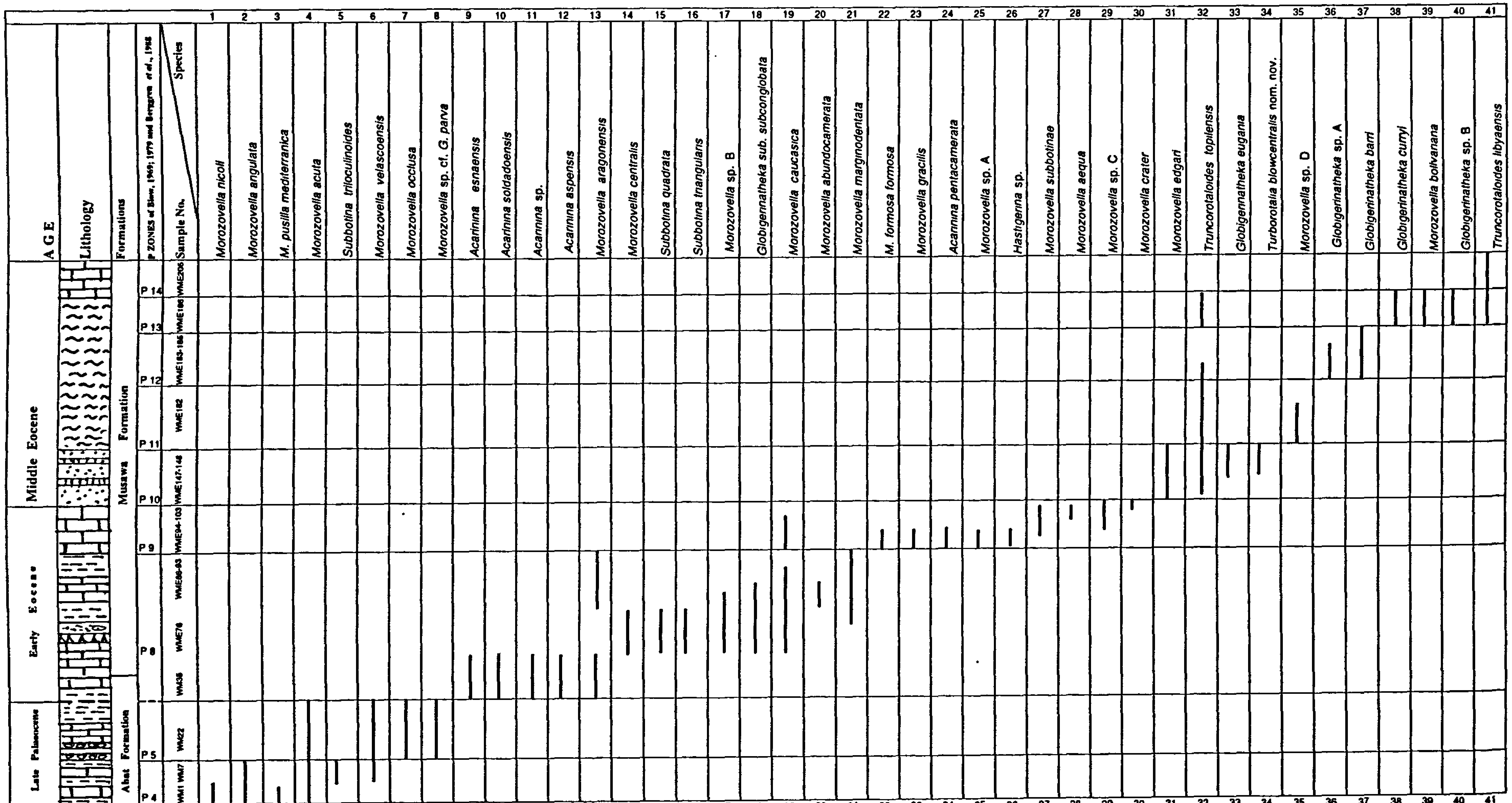
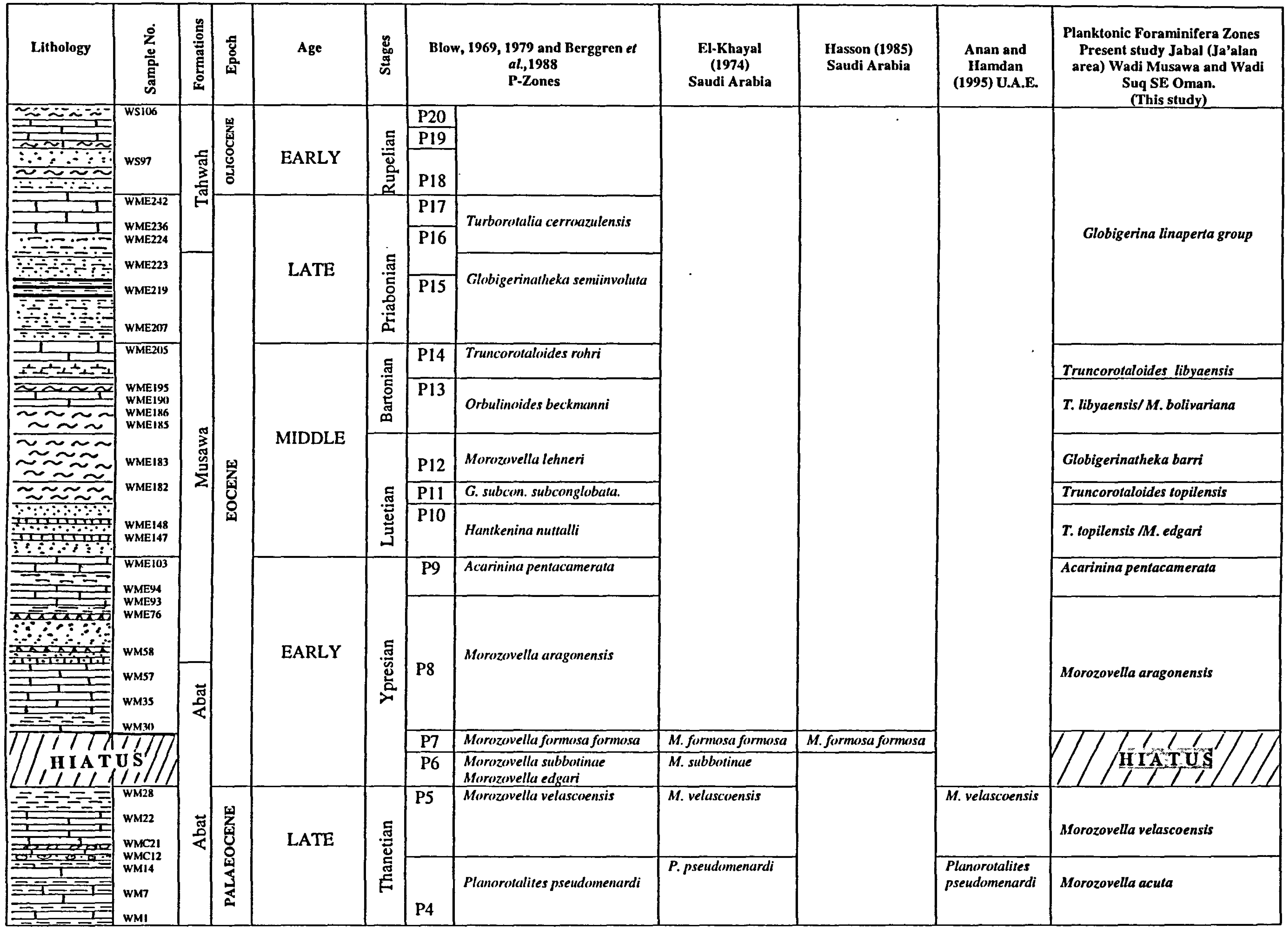



**Fig. 6.3 Distribution of the planktonic foraminiferal fauna (Upper Palaeocene to Middle Eocene) in the Wadi Musawa section.**
*(NB. Barren sections left out and section collapsed)* Lithology not to scale




*(Lithology not to scale)*

**Fig. 6.4 Late Palaeocene to Middle Eocene planktonic foraminiferal zonation in Wadi Musawa and correlation with standard zones of Blow, 1969; 1979 and Berggren *et al.*, 1988 and correlate with equivalent horizons in Saudi Arabia and United Arab Emirates.**

| SAMPLE NO. | LITHOLOGY | FORMATIONS | EPOCH | STAGES | AGE | BLOW, 1969; 1979 and Berggren *et al.*, | Present study Planktonic Foraminifera | Present study Larger Foraminifera |
|---|---|---|---|---|---|---|---|---|
| WS106 | | Tahwah | Oligocene | Rupelian | EARLY | P20 | *Globigerina linaperta group* | *Nummulites fichteli*<br>*Lepidocyclina (Eulepidina)* sp.<br>*L. (Nephrolepidina)* sp. |
| | | | | | | P19 | | |
| WS97 | | | | | | P18 | | |
| WME242 | | | Eocene | Priabonian | LATE | P17 | *Globigerina linaperta group* | *Nummulites striatus*<br>*Gypsina* sp<br>*Discocyclina javana* |
| WME236<br>WME224 | | | | | | P16 | | |
| WME223<br>WME207 | | Musawa | | | | P15 | | |
| WME205 | | | Eocene | Lutetian | MIDDLE | P14 | *Truncorotaloides libyaensis* | *Nummulites* cf. *schaubi*<br>*Nummulites maculatus*<br>*Discocyclina aff. D. javana*<br>*Discocyclina* cf. *D. dispansa* |
| WME195<br>WME190<br>WME186<br>WME185 | | | | | | P13 | *Globigerinatheka sp. B*<br>*Globigerinatheka curryi*<br>*Morozovella bolivariana*<br>*Truncorotaloides libyaensis*<br>*Truncorotaloides topilensis* | |
| WME183 | | | | | | P12 | *Truncorotaloides topilensis*<br>*Globigerinatheka barri*<br>*Globigerinatheka* sp. A | *Linderina* sp. A<br>*Linderina* sp. B<br>*Gypsina globulus*<br>*Neorotalia omanensis sp nov.* |
| WME182 | | | | | | P11 | *Truncorotaloides topilensis*<br>*Morozovella sp. D* | *Nummulites discorbinus* |
| WME148<br>WME147 | | | | | | P10 | *Turborotalia blowcentralis nom. nov.*<br>*Truncorotaloides topilensis*<br>*Globigerinatheka euganea*<br>*Morozovella edgari* | *Coskinolina balsillei* |
| WME103<br>WME94 | | | Eocene | Ypresian | EARLY | P9 | *Morozovella* sp. C<br>*Morozovella aequa*<br>*Morozovella crater*<br>*Morozovella subbotinae*<br>*Morozovella caucasica*<br>*Acarinina pentacamerata*<br>*M. formosa formosa*<br>*Morozovella gracilis*<br>*Morozovella marginodentata*<br>*Morozovella* sp. A<br>*Hastigerina* sp. | *Dictyoconus egyptiensis*<br>*Nummulites* cf *atacicus*<br>*Dictyoconus egyptiensis* |
| WME93<br>WME76<br>WM58<br>WM57<br>WM35<br>WM30 | | Musawa / Abat | | | | P8 | *Morozovella caucasica*<br>*Morozovella aragonensis*<br>*Morozovella marginodentata*<br>*M. abundocamerata*<br>*G. sub. subconglobata*<br>*Subbotina quadrata*<br>*Subbotina triangularis*<br>*Morozovella centralis*<br>*Morozovella* sp. B<br>*G. sub. subconglobata*<br>*Acarinina soldadoensis*<br>*Acarinina esnaensis*<br>*Acarinina aspensis*<br>*Acarinina* sp. | *Nummulites fossulata*<br>*Ranikothalia sp.*<br>*Lockhartia sp.*<br>*Operculina musawaensis nov.*<br>*Asterocyclina sp. B*<br>*Nummulites globulus*<br>*Alveolina katicae*<br>*Nummulites honogoensis* |
| | HIATUS | | | | | P6/P7 | HIATUS | |
| WM28<br>WM22 | | Abat | Palaeocene | Thanetian | LATE | P5 | *Morozovella velascoensis*<br>*Morozovella acuta*<br>*Morozovella occlusa*<br>*Morozovella* sp. cf *M. parva* | *Miscellanea primitiva*<br>*Daviesina shirazensis*<br>*Daviesina iranica*<br>*Asterocyclina* sp. A |
| WMC21<br>WMC12<br>WM14<br>WM7<br>WM1 | | | | | | P4 | *Morozovella velascoensis*<br>*Morozovella acuta*<br>*Subbotina triloculinoides*<br>*M. pusilla mediteranica*<br>*Morozovella nicoli*<br>*Morozovella angulata* | *Miscellanea primitiva*<br>*Asterocyclina* sp. A<br>*Daviesina shirazensis*<br>*Daviesina iranica* |

**Fig 6.5 Late Palaeocene to early mid-Oligocene planktonic and larger foraminiferal assemblages in Wadi Musawa and Wadi Suq sections, correlated with Blow, 1969; 1979 and Berggren *et al.*, 1988.**
(Lithology not to scale)


Fig. 6.6 Distribution of larger foraminifera from the Wadi Musawa and Wadi Suq sections. *(Lithology not to scale)*

## 6.9 Palaeobiogeographic Significance of Oman larger foraminiferal fauna

Previous workers e.g Racey (1995) have demonstrated that the Oman nummulitid fauna shows a marked mixing of Mediterranean and Indo-West Pacific taxa as one might expect based on the geographic location of Oman between these faunal provinces. This work although based on a more poorly developed and poorly preserved assemblage, supports this idea. Within the Palaeocene section most taxa identified appear to be mainly restricted to the Middle East. Younger taxa (Lower to Upper Eocene) are mainly known from the Indian subcontinent and Mediterranean areas whilst Oligocene species such as *Nummulites fichteli* are known to be cosmopolitan in their distribution (Fig. 6.7).

| Species | Area |
|---|---|
| *Nummulites* cf *atacicus* | Mediterranean, East Africa, India, Middle East and U.S.S.R. |
| *Nummulites discorbinus* | |
| *Nummulites fichteli* | Mediterranean, Indo-West Pacific |
| *Nummulites fossulata* | Afghanistan and Oman |
| *Nummulites* cf. *honogoensis* | Japan and Oman |
| *Nummulites maculatus* | India and Oman |
| *Nummulites striatus* | Mediterranean, East Africa, Oman and Iran |
| *Miscellanea primitiva* | Iran and Oman |
| *Daviesina iranica* | Iran, Oman and China |
| *Daviesina shirazensis* | Iran and Oman |
| *Discocyclina* cf. *dispansa* | India and Pakistan |
| *Dictyoconus egyptensis* | Egypt, Iran, Iraq, Oman, Somalia, Pakistan and India |
| *Coskinolina balsillei* | Oman and Baluchistan |
| *Alveolina katicae* | Oman |
| *Gypsina globulus* | India and Oman |

**Fig. 6.7 Palaeobiogeographic distribution of Larger Foraminifera from the Wadi Musawa Section.**

# *Chapter Seven*
# *Palaeoenvironments*

## *Chapter Seven*

# PALAEOENVIRONMENT

## 7.1 Introduction

Larger Foraminifera are among the most useful fossils for palaeoecological work in shallow marine environments due to their wide geographic range and abundance coupled with the large amount of literature on modern larger foraminiferal ecology. A general discussion on larger and planktonic foraminiferal palaeoenvironments is given in Chapter Three for each lithostratigraphic unit. Since the palaeoenvironmental interpretation is based on a single measured section it must be treated with some degree of caution as lateral variations in facies and faunas have not been studied. Moreover, the detailed sedimentology and facies modelling is the topic of separate Phd (Al-Harthy in prep). In addition the hardness of many of lithologies made it impossible to obtain reasonable quantitative data on the microfauna through routine sample processing.

Consequently, routine methods of palaeoenvironmental analysis such as Murray triangular diagrams (Murray, 1973) have not been possible. Even where it was possible to extract the microfauna the planktonic Foraminifera were often broken whilst the larger Foraminifera were often broken, silicified and/or bored making identifications ( even in some cases to generic level) difficult. Bearing in mind these problems and the varying degrees of uncertainty concerning the actual faunal assemblages present the following palaeoenvironmental interpretations are by necessity broad and are not discussed in detail.

## 7.2 PALAEOECOLOGY

Since benthonic Foraminifera are mainly bottom dwellers with limited movement they are often preserved approximately in situ and are thus useful for reconstructing depositional environments. Larger foraminiferal genera often show distinctive depth related differences in their distribution. It is, of course, not water depth but the factors which vary with water depth such as substrate type, water energy, light intensity etc which control the distribution of the larger benthic Foraminifera as noted by Reiss and Hottinger (1984).

### 7.3 FORAMINIFERAL PALAEOECOLOGY

Murray (1991) noted that the main factors influencing the distribution of living benthonic Foraminifera are salinity, depth, temperature, substrate and light intensity. Light intensity and water depth are especially important since many species are believed to possess algal symbionts. Each of these factors is briefly discussed below:

#### 7.3.1 Salinity

Hallock and Glenn (1985) observed that Recent rotaliid Foraminifera are typically stenohaline, with salinities ranging from 30-40ppt whilst Reiss and Hottinger (1984) recorded abundant Recent rotaliids including nummulitids and amphisteginids in the Gulf of Elat where salinities range from 40-41ppt. The shallow-dwelling, living, porcellaneous, larger Foraminifera such as peneroplids, miliolids and alveolinids are common in lagoons and other low-energy environments and are capable of tolerating higher than normal marine salinities (Murray, 1973; Chaproniere, 1975). Murray (1973) demonstrated that assemblages containing abundant, low diversity, miliolid assemblages with rare rotaliid Foraminifera may indicate hypersaline conditions as observed in the *Peneroplis* dominated fauna of the Persian Gulf.

#### 7.3.2 Depth

Phleger (1960) regarded water depth as one of the most important factors, with different benthonic Foraminifera occupying various depth intervals.

Hottinger (1977) observed that Recent porcellaneous Foraminifera from the Red Sea, such as miliolids (*Quinqueloculina*), occurred in shallow waters from a few meters to 50 meters. Haynes (1965) suggested that the random orientation of calcite crystals in porcellaneous test may have allowed scattering of "harmful" ultra-violet radiation, thus permitting photosynthesis in shallower waters. Haynes (1965) also noted that at <5m depth photosynthesis by algal symbionts was markedly reduced and he attributed this to damage by short-wave length of radiation.

Hottinger (1977) noted that genera which have perforate tests, such as *Operculina* and *Heterostegina*, occupy a broad depth range (from 50-100m) though they are most abundant in the deeper shelf water. Racey (1988) showed that fossil perforate genera such as *Nummulites*, *Assilina*, *Lockhartia*, *Operculina* and *Discocyclina* from Oman appeared to occupy a range of mid to outer shelf environments.

Wray (1977) showed that the calcareous algae which are often found in association with larger Foraminifera are useful as water-depth indicators, because of their sensitivity to light penetration and because different algal groups use different wavelengths of light for photosynthesis. Reiss and Hottinger (1984) in their study of Recent larger Foraminifera from the Gulf of Aqaba, noted that the alveolinid *Borelis schlumbergeri* occurred most frequently between 25-35m; the nummulitids *Heterostegina depressa* and *Operculina ammonoides* between 20m (most common at 40-60m and 30m respectively); whilst the soritids ranged from 0-50m. The depth distribution of these living larger Foraminifera is likely to be controlled by the type of symbionts they possessed (Murray, 1991)

### 7.3.3 Temperature

Temperature is a critical factor for successful reproduction. Temperature decreases with increasing water depth and is partly controlled by the distribution of the major current systems. Current marine temperatures are classified into five categories (Vaughan, 1940) as follows:

| | |
|---|---|
| a- Polar zone | 1.9-5°C |
| b- Sub-polar zone | 5 – 10°C |
| c- Temperate zone | Maximum temperature 25°C |
| d- Sub-tropical zone | 15 –33°C |
| e- Tropical zone | 25 – 36°C |

Larger Foraminifera are predominantly Tropical to Subtropical in their distribution.

### 7.3.4 Light

This factor is vital for most organisms and especially for algal symbiont-bearing larger Foraminifera with different algal symbionts having different preferences for certain wavelengths of light and thus different water depth. Light penetration is greatest at the tropics and thus this is where larger Foraminifera tend to be most common.

## 7.4 WADI MUSAWA AND WADI SUQ PALAEOENVIRONMENTS

### a) Abat Formation

The Late Palaeocene to Early Eocene (Thanetian to Ypresian) Abat Formation comprises a thick sequence of deep, open marine basinal sediments. The lithology, fauna and biofacies have been described in Chapter 3. A summary of the environments recognised is as follows:

Common deep marine planktonic foraminiferal shales and mudstones form the lower part and shallow upwards into fairly high energy mid outer shelf/platform limestones dominated by larger Foraminifera including *Assilina, Nummulites, Alveolina, Discocyclina, Daviesina, Miscellanea* and *Operculina musawaensis* nov. sp., plus smaller benthonic Foraminifera including *Lenticulina, Nodosaria, Glandulina, Anomalinoides*, and *Pullenia*. Dasycladacean algae, calcareous red algae together with echinoid plates and corals occur sporadically throughout this upper part supporting this interpretation.

The Late Palaeocene to Early Eocene fauna from sample WM1 to WM57 comprises diverse planktonic Foraminifera, which make up about (30%), small benthonic Foraminifera (10%) and larger Foraminifera which are often penecontemporaneously redeposited (60%). The larger Foraminifera are pyrite infilled and become progressively more abraded up section. Reworked Cretaceous Radiolaria and charophytes also occur within this interval (Fig. 7.2).

### b) Musawa Formation

The Early to Late Eocene (Ypresian to Upper Bartonian) Musawa Formation comprises a regressive siliciclastic package at its base and is transgressive at its top (see Chapter Three). It shows a mix of alternating continental fluvial sandstones, palaeosols and shales and mudstones with planktonic Foraminifera, re-deposited larger Foraminifera and reworked radiolaria. Reworked radiolaria and charophytes tend to occur together, especially in the fluviatile, coal seam cycles (Fig. 7.2). The middle part of the formation represents an outer shelf environment which shallows upwards.

The lower part of the formation is characterised by deep, open marine planktonic Foraminifera including *Morozovella abundocamerata, M. aragonensis M. caucasica, M. formosa formosa, M. gracilis, M. marginodentata,* and *M. subbotinae*. The middle part of the formation containing planktonic Foraminifera including *M. edgari, Globigerinatheka euganea, G. barri, G. curryi, Truncorotaloides topilensis, T. libyaensis* and *Turborotalia blowcentralis* nom. nov.

The upper part of the formation represents a shallow marine, outer shelf environment with common in *in-situ* larger Foraminifera including *Nummulites, Operculina, Discocyclina, Dictyoconus, Coskinolina,* and *Neorotalia omanensis* nov. sp. which represent the only *in-situ* larger Foraminifera in this formation. Bivalves and gastropods in this upper part are indicative of an intertidal to tidal flat environment (N. Morris pers. comm. 1998). The uppermost part of the formation comprises a shallow fairly restricted, inner shelf facies with miliolids and molluscs which become more estuarine dominated towards its top as indicated by the presence of coal seams and changes in ostracod fauna (Fig. 7.2).

**c) Tahwah Formation**

The Late Eocene to Early mid-Oligocene (Priabonian) Tahwah Formation comprises a regressive carbonate dominated unit with sandstone intervals (see Chapter Three), and ranges from Upper Bartonian (*Nummulites striatus* and *Discocyclina javana*) to Oligocene [*Nummulites fichteli, Lepidocyclina* (*Nephrolepidina*) and *Lepidocyclina* (*Eulepidina*)]. Within the studied sections some (if not all) the larger Foraminifera have been redeposited into relatively deeper water environments. Environments range from shallow marine, fairly high energy mid shelf at its base with *Nummulites* and *Discocyclina* to slope deposits at the top (with reworked larger Foraminifera especially *N. fichteli* and *Lepidocyclina*).

An attempt was made to fit the results to the general limestone ramp model suggested for the Middle Eocene Seeb Limestone (Racey, 1988).

With the exception of units A, B, C and D, F, G (part), H, I, M, N and O, larger Foraminifera are mainly redeposited albeit penecontemperaneously.

A brief description of the palaeoenvironment for each of these units bearing in-situ larger Foraminifera is given below:

Palaeogene larger Foraminifera show a general depth zonation at generic level from textulariids and miliolids (shallowest), *Somalina, Alveolina, Nummulites, Assilina* to *Discocyclina* (deepest). This is illustrated schematically in Fig. 7.1.

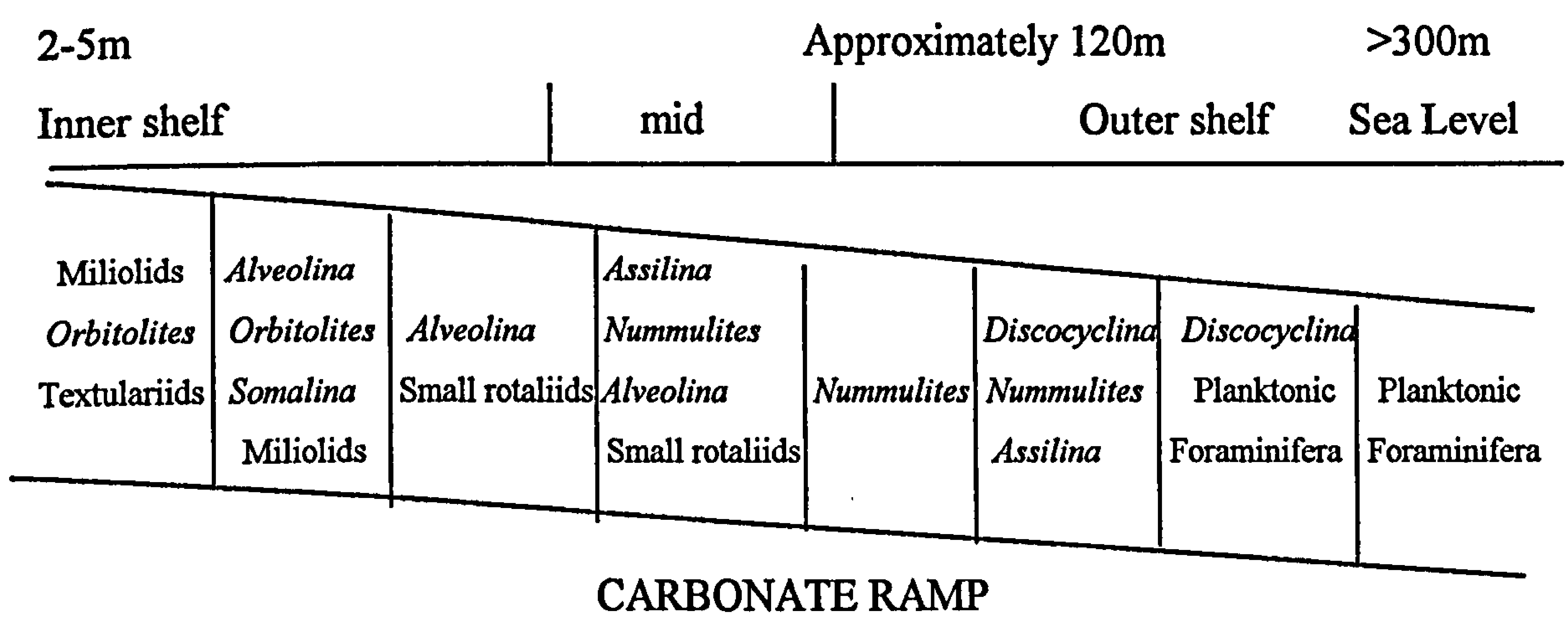



**Fig. 7.1 Depth related larger foraminiferal distribution within the Wadi Musawa Section. Fauna listed in order of decreasing abundance. Figure not to scale.**

**Unit A**

This comprises a sequence of shales and mudstones containing common planktonic and smaller benthic Foraminifera deposited in a deep open marine environment and is capped by wackestones and packstones containing larger rotaliids (*Miscellanea, Daviesina, Discocyclina* and *Assilina*), small rotaliids, red algae, corals and echinoid spines suggesting a shallow marine fairly high energy open marine outer shelf environment.

**Unit B**

This comprises mainly represent calciturbidite and slope deposits based on their sedimentary structures with bioclasts derived from a shallow marine mid-outer platform (containing common larger rotaliid Foraminifera), redeposited broken miliolids and smaller rotaliids with in-situ unbroken *Nummulites* and *Discocyclina* plus calcareous red algae indicative of an outer shelf environment. Since this unit is interpreted as being deposited in a slope depositional setting the absence of planktonic Foraminifera within this unit may indicate that the basin was not open to deep marine circulation.

**Unit C**

Planktonic foraminiferal mudstones and wackestones at the base were deposited in a deep marine environment and are overlain by shales containing redeposited miliolids, and in-situ *Alveolina* and *Nummulites* indicating a more mid shelf environment.

**Unit D**

The unit shows a gradual change from deep marine basinal facies rich in planktonic Foraminifera in its lower part into shallow marine mid-outer shelf limestones with *Nummulites*, *Assilina* and *Discocyclina* plus rare dasycladacean green algae (fragments) in its upper part and is capped by unfossiliferous shales of probable fluvial origin and palaeosols. Ostracods from samples WM34-WM40 include *Bairdia* and *Cytherella*, which occur from near shore to circalittoral environment and thus do not indicate any particular shelf environment. The presence of *Phalcocythere* and *Xestoleberis* in samples WM37 and WM40 suggest shallow marine environments (Dr. M. Keen pres. com.).

**Unit F**

Comprises mainly planktonic foraminiferal mudstones and wackestones with *Nummulites* in its lower part indicating a fluctuating fairly deep marine outer shelf environment. The middle part comprises abundant smaller benthic Foraminifera plus *Nummulites* and *Assilina* indicating an outer/middle shelf environment. The upper part contains alternating mudstones and wackestones with miliolids, smaller rotaliids plus gastropods, corals and ostracods indicative of an inner shelf environment.

**Unit G**

In samples WME146-148 within the middle part of this dominantly fluvial unit an interval rich in *Discocyclina, Alveolina, Nummulites* and planktonic Foraminifera indicates a rapid marine incursion (flooding surface) which reached at least outer shelf water depths.

**Unit H**

Thick shale unit rich in planktonic Foraminifera (particularly diverse at the base of the unit) is indicative of a deep marine environment together with common *Nummulites, Operculina* and *Discocyclina* that become more common towards the top of the unit and are indicative of a (mid-) outer shelf environment. The topmost part contains molluscs typical of a intertidal/subtidal setting (Dr. N. Morris, pers. comm.) suggesting continued shallowing.

**Unit I**

Wackestones and mudstones dominate the lower part with common planktonic Foraminifera indicative of a deep marine environment and pass upwards into *Nummulites* and *Operculina* wackestones indicative of a more middle shelf setting. Mudstones and wackestones towards the top of the unit contain a mollusc fauna typical of a low intertidal to subtidal environment (Dr. N. Morris, pers. comm. 1998).

**Unit M**

Deep marine (?slope) based on the presence of common planktonic Foraminifera of the *Globigerina linaperta* group with common intervals of resedimented *Nummulites.* The button corals present are typical of deeper water (slope) environments (Dr. B. Rosen, pers. comm.).

**Unit N**

Wackestones with common *Nummulites, Discocyclina*, calcareous red algae and planktonic Foraminifera are indicative of deposition in a outer shelf setting.

### Unit O

Mainly slope (debris flows) deposits containing common *Lepidocyclina, Nummulites* and colonial corals mixed with planktonic Foraminifera.

## 7.5 Conclusion

The section is interpreted as having been deposited in a range of environments from deep open marine to shallow marine to fluvial. The high species diversity observed is due to a mixing of *in-situ* faunas with resedimented faunas suggesting that the section was deposited in an environment which was tectonically active, with marked oscillations in sea level.

Fig. 7.2 Number of specimens of the five major components of the microfaunas from the Wadi Musawa and Wadi Suq sections, SE Oman.

# *Chapter Eight*
# *Conclusions*

# *Chapter Eight*
# CONCLUSIONS

The Lower Tertiary deposits of the Wadi Musawa Section Southeast Oman exhibit a wide range of depositional environments, from basinal through slope to shelf and fluvial.

Three formations have been recognised on lithological criteria and dated accurately for the first time mainly on the basis of their contained planktonic foraminifera, whilst larger benthonic foraminifera were identified to assist age assignments where planktonic foraminifera were absent. Planktonic foraminifera are more abundant and diverse than the associated larger foraminiferal fauna.

1- The Wadi Musawa and part of the Wadi Suq sequences are described in detail for the first time with three formations recognised (the Abat, Musawa and Tahwah) which are subdivided into fifteen units (A-O).

2- The Abat Formation comprises four lithostratigraphic units, of which the lowest unit A comprises mainly shales and mudstones and was deposited in a deep, open marine basinal environment in the Late Palaeocene. The B, C and D units comprise a range of facies representing Upper Palaeocene to Lower Eocene shallow to mid-outer shelf environments.

3- The Musawa Formation comprises seven lithostratigraphic units E-L. It comprises three mainly fluvial packages with interbedded limestones, shales, siltstones and coals representing a range of Lower to Upper Eocene environments from continental fluvial to deep marine, marginal marine, outer shelf and estuarine.

4- The Tahwah Formation comprises four lithostratigraphic units M-O. The formation is dominated in its lower part by sandstone and siltstone, the middle part comprises mainly shales to marls interbedded with thin layers of limestone whilst the upper part comprises siltstones and limestones. This formation was deposited in a range of environments from shallow marine outer shelf to deep slope during the Upper Eocene to lower part of the mid-Oligocene.

5- Forty-one planktonic foraminifera comprising seven genera are described and illustrated for the first time from Oman. Of these 10 are new to the Middle East.

The Lower and Middle Palaeocene zones appear to be missing in the studied section (P1-P3) as is common throughout most of the Arabian Peninsula and Gulf (Jones and Racey, 1995). In this study the missing the Lower Eocene zones P6 and P7 suggest a hiatus, similar to that observed in the eastern Oman Mountains on the Batinah Coast between the Lower and Upper Jafnayn Formation Members (Racey, 1995; Al-Sayigh and Racey in prep.) as shown in Fig. 2.9.

The planktonic Foraminifera allow a provisional zonation to be established, calibrated to the international Upper Palaeocene and Middle Eocene planktonic foraminiferal zones of Blow, 1969; 1979 and Berggren *et al.*, 1988 (P zones). Only three of Blow's (1969, 1979) zones could be recognised on the occurrence of their nominate species (zones P5, P8 and P9). For this reason it was desirable to erect a local zonation, using the known ranges of the species present. The known stratigraphic distribution of these species was used to recognise the zones P5, P8-P9 as equivalent to standard zones of Blow, 1969, 1979, while strata considered generally equivalent to P4 and P10-P14 in the Wadi Musawa section are zoned on the basis of the local range (Fig. 6.1). These zones from bottom to top comprise:

1- *Morozovella acuta* Zone (P4).
2- *Morozovella velascoensis* Zone (P5).
3- *Morozovella aragonensis* Zone (P8).
4- *Acarinina pentacamerata* Zone (P9).
5- *Truncorotaloides topilensis/Morozovella edgari* Zone (P10).
6- *Truncorotaloides topilensis* Zone (P11).
7- *Globigerinatheka barri* Zone(P12).
8- *Truncorotaloides libyaensis/Morozovella bolivariana* Zone (P13).
9- *Truncorotaloides libyaensis* Zone (P14).

6- The foraminifera and lithostratigraphy permit tentative identification of sea level cycles globally recognised from the Palaeocene to Lower Oligocene.

7- *Globorotalia (Turborotalia) praecentralis* Blow 1979 is shown to occur in Oman but is demonstrated to be a primary homonym of *G. praecentralis* Haque 1966. It is thus renamed *Turborotalia blowcentralis* nom. nov.

8- Twenty seven species of larger foraminifera are identified and described and their ranges used to supplement the planktonic foraminiferal zonation.

9- Two new species of larger foraminifera *Neorotalia omanensis* and *Operculina musawaensis* are described and illustrated.

10- The occurrence of mixed faunal assemblages and rapid vertical changes in facies in the Wadi Musawa sequence indicates a substantial periods of time during which penecontemporaneous uplift and resedimentation of carbonate shelf deposits occurred as is typical in strike-slip terranes.

11- The ages of the larger Foraminifera (where identifiable) generally agree well with the associated planktonic Foraminifera suggesting that the former are penecontemporaneously redeposited.

12- The lithological changes observed are mainly of local tectonic origin as has been demonstrated by recent unpublished mapping (Hanna *et al*). Sedimentary structures indicative of storms such as hummocky cross stratification have not been observed whilst gravity driven structures (turbidites) are comparatively rare.

13- In strike-slip terranes such as seen at Jabal Ja'alan major changes in facies associated with pull-apart (transtension) and pop-up structure (transpression) are frequently observed (Hanna, pers. comm; Wright, pers comm.).

14- The work concentrates primarily on the Upper Palaeocene-Upper Eocene Wadi Musawa Section from which sixty-six foraminiferal species were identified. The Wadi Suq Section is complementary and was collected to extend the sequence into the Lower Oligocene though only 2 species of larger foraminifera plus plankton of the *Globigerina linaperta* group were recovered from this interval.

15- The chronostratigraphic boundaries between these formations differ from those previously published. In particular, the boundary between the Abat and Musawa formations is redefined as younger. The age of the Abat Formation is shown to range from Upper Palaeocene (P4 and P5) to Lower Eocene (P8) rather than Upper Palaeocene to Middle Eocene as published by Roger *et al.* (1991). The Musawa Formation is redated as Lower Eocene (P8) to Upper Eocene (P15/16) rather than Middle to Upper Eocene as previously published (Roger *et al.,* 1991).

16- Palaeobiogeographically, the Upper Palaeocene larger foraminifera species identified to be restricted to the Middle East, whilst the Eocene taxa also occur in the Indian Subcontinent and in the Mediterranean; Oligocene taxa, such as *Nummulites fichteli*, are cosmopolitan (see Fig. 6.5).

17- Previous workers have identified (but not illustrated) a limited microfauna from this area of Oman comprising four planktonic foraminifera: *Morozovella velascoensis, M. quetra, Acarinina mckanni, A. soldadoensis* and *Globigerina velascoensis* and eleven larger Foraminifera: *Alveolina pasticillata, Miscellanea miscella, Nummulites discorbinus, N.* aff. *gallensis, N.* cf. *lehneri, N. praediscorbinus, Sakesaria cotteri, Nummulites bullatus, N. fabianii, N. garnieri and Spiroclypeus margaritus*. This compares with the forty-one planktonic and twenty-seven larger foraminifera described and illustrated herein.

18- The Omani sequence contains more planktonic foraminiferal species and more zones than previously recognised from the adjacent regions i.e. Saudi Arabia and Emirates (see Fig. 6.4).

19- *Acarinina soldadoensis, Morozovella velascoensis* and *Nummulites discorbinus* are the only taxa common to both previously published work and this work.

20- *Linderina* is poorly known from the Arabia and Gulf region. Previously published illustration in the Ellis and Messina Catalogue coupled with my own observation, suggests that the globular forms with umbonal lamellar thickening are all megalospheric whilst the discoidal forms appear to be microspheric. Previous authors e.g. (Singh, 1953) have attributed these two test shape to difficult species.

21- The interesting microfossil (*Incertae sedis*) has some similarity to *Bolboforma* but the Omani specimens were difficult to equate with that enigmatic organism due to their distinctive conical shape and ornament.

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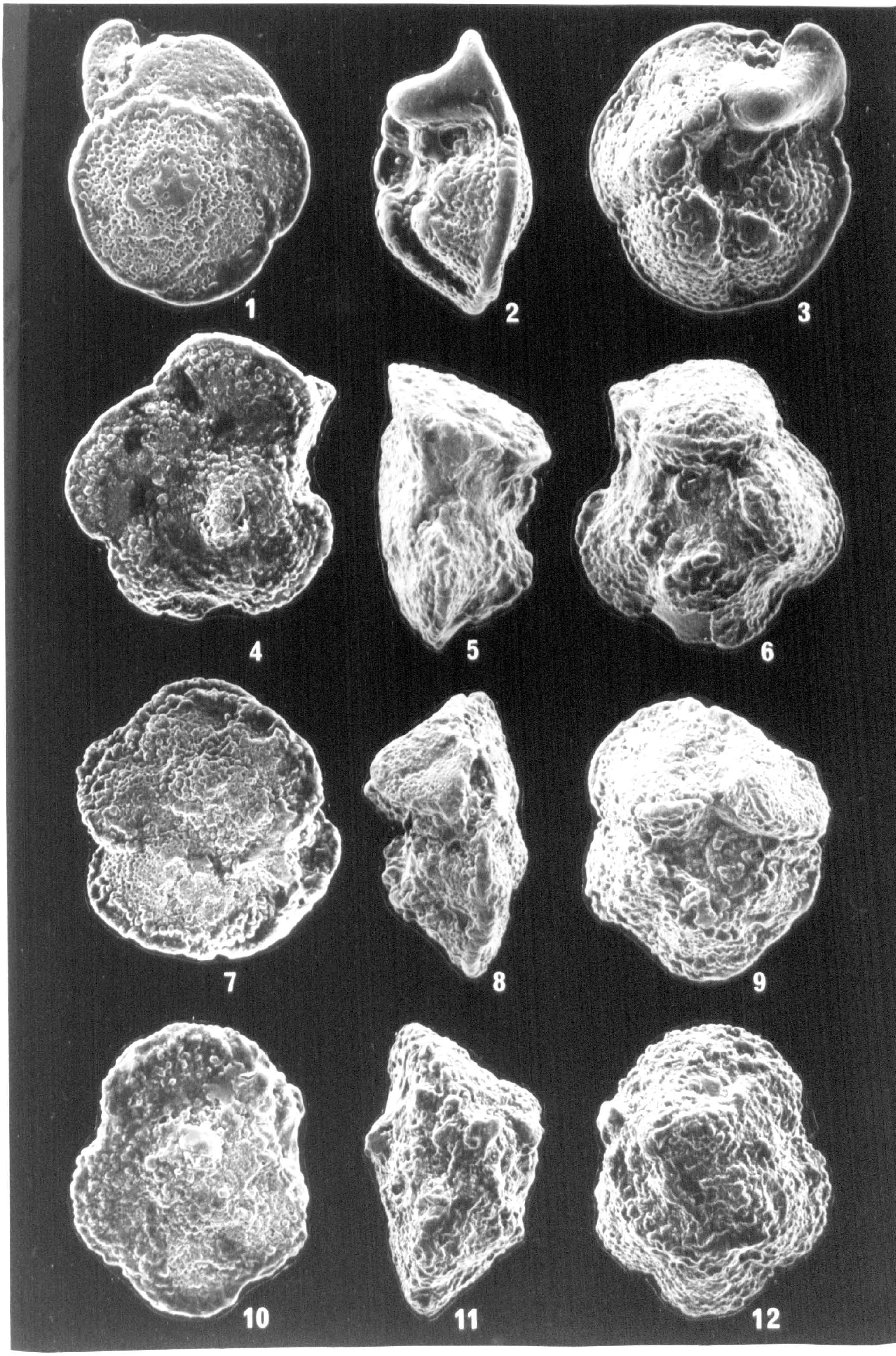
# *Plates*

## Plate 1

Figs. 1-3 *Morozovella abundocamerata* (Cushman, 1928). . From sample WME 86, Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x160. (See p. 83)

Figs. 4-12 *Morozovella acuta* (Toulmin, 1941). From sample WM 1, WM 7 and WM 22, respectively. All from the Wadi Musawa Section, Jabal Ja'alan area, SE Oman Late Palaeocene. Three specimens in spiral, edge and umbilical view, respectively. Figs. 4-6, x120, 7-9, 130, 10-12, x125. (See p. 85).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## Plate 2

Figs. 1-3 *Morozovella aequa* (Cushman & Renz, 1942). From sample WME 99. Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x215. (See p. 87).

Figs. 4-6 *Morozovella angulata* (White, 1928). From sample WM 1 and WM 7. Wadi Musawa Section, Jabal Ja'alan area, SE Oman Late Palaeocene. Spiral, edge and umbilical views, respectively, x155. (See p. 89).

Figs. 7-12 *Morozovella aragonensis* (Nuttall, 1930). From samples WM 35, WME 86 and WME 95, respectively. All from the Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Early Eocene. Two specimens in spiral, edge and umbilical view, respectively. Figs 7-9 x110; 10-12, x145. (See p. 90).

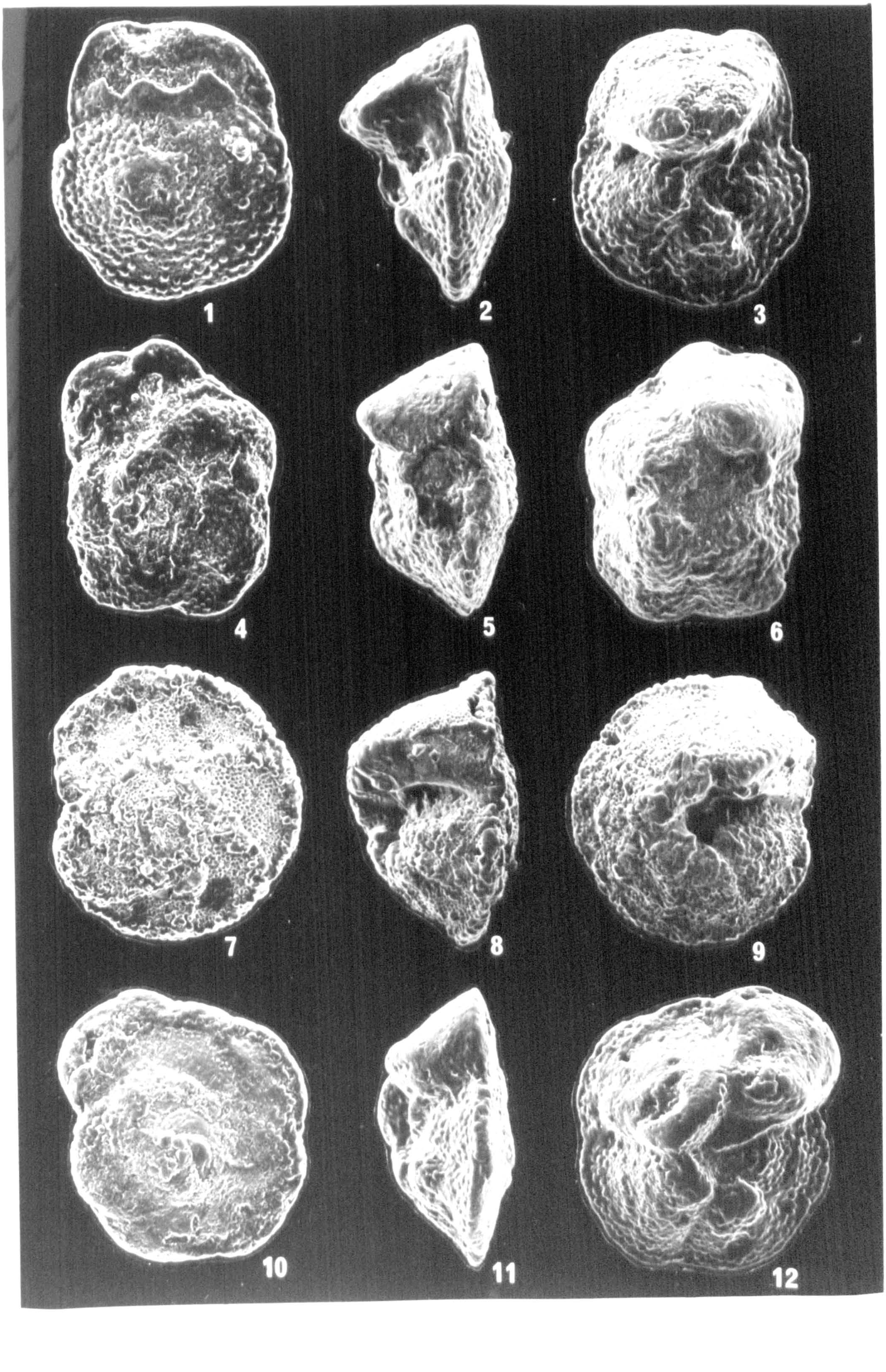
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**Plate 3**

Fig. 1-3 *Morozovella bolivariana* (Petters, 1954). From sample WME 186, Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Middle Eocene. Spiral, edge and umbilical views, respectively, x125. (See p. 92).

Figs. 4-12 *Morozovella caucasica* (Glaessner, 1937). From samples WME 76, WME 86 and WME 98, respectively. All from Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Early Eocene. Three specimens in spiral, edge and umbilical view, respectively. Figs. 4-6, x125; 7-9, x95; 10-12, x115. (See p. 93).

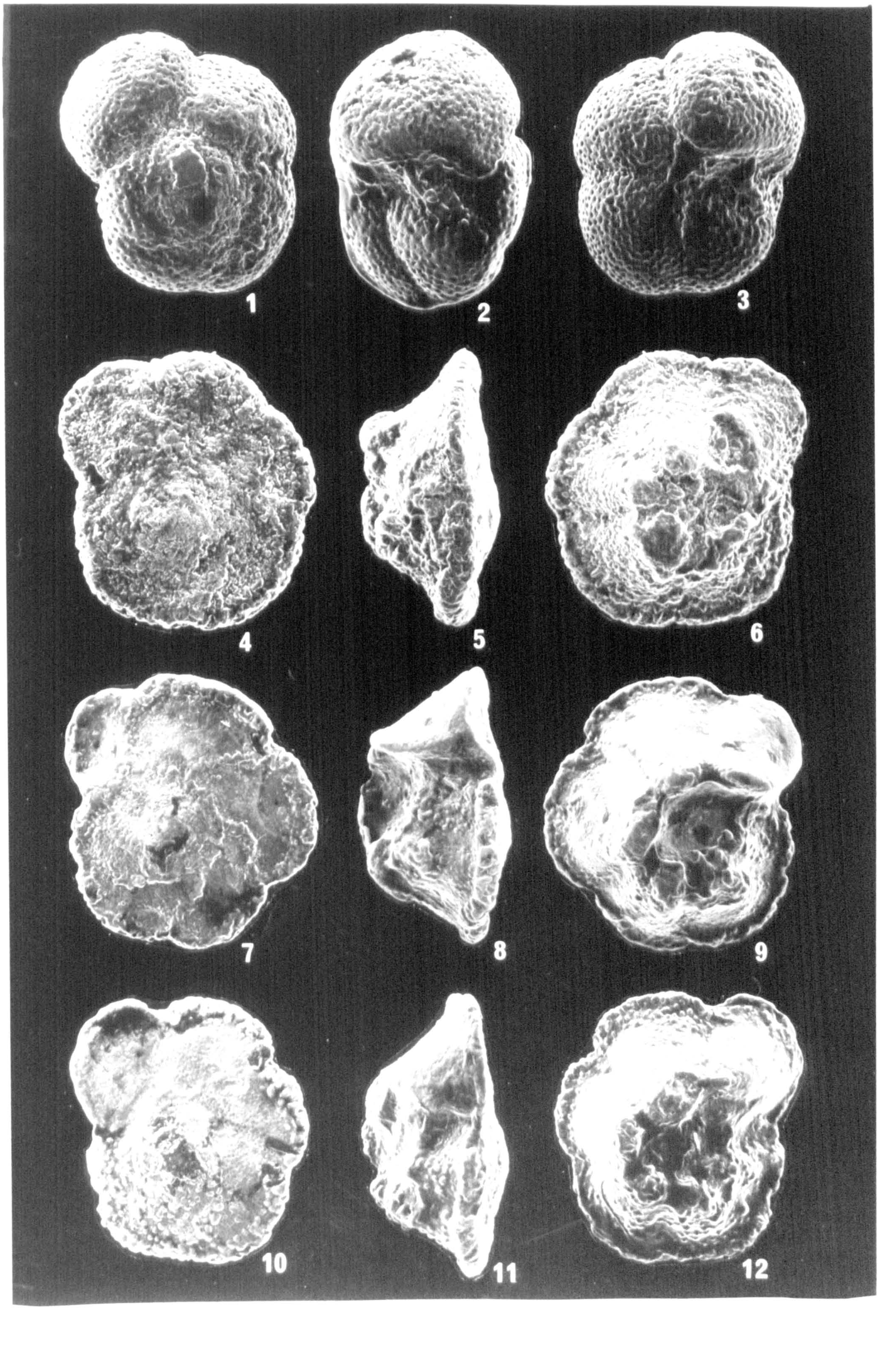
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**Plate 4**

Figs. 1-6 *Morozovella caucasica* (Glaessner, 1937). From samples WME 76 and WME 86, respectively. Both from the Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Early Eocene. Two specimens in spiral, edge and umbilical view, respectively. Figs. 1-3, x135; 4-6, x140 (See p. 93).

Figs. 7-9 *Morozovella crater* (Finlay, 1939). From sample WME 103,. Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Early Eocene Spiral, edge and umbilical views, respectively, x175. (See p. 97).

Figs. 10-12 *Morozovella edgari* (Premoli Silva & Bolli, 1973). From sample WME 148, Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Middle Eocene. Spiral, edge and umbilical views, respectively, x180. (See p. 98).

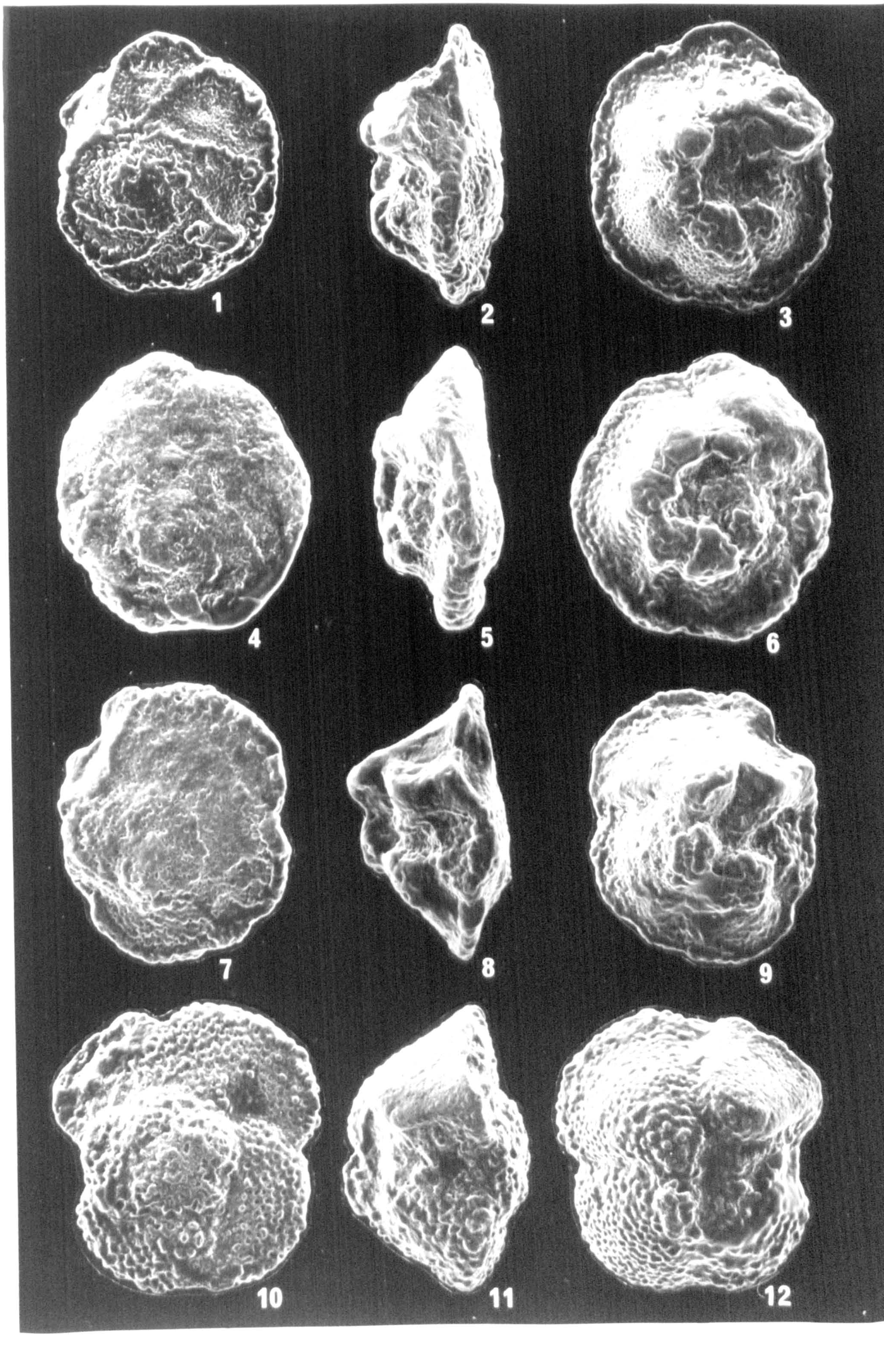

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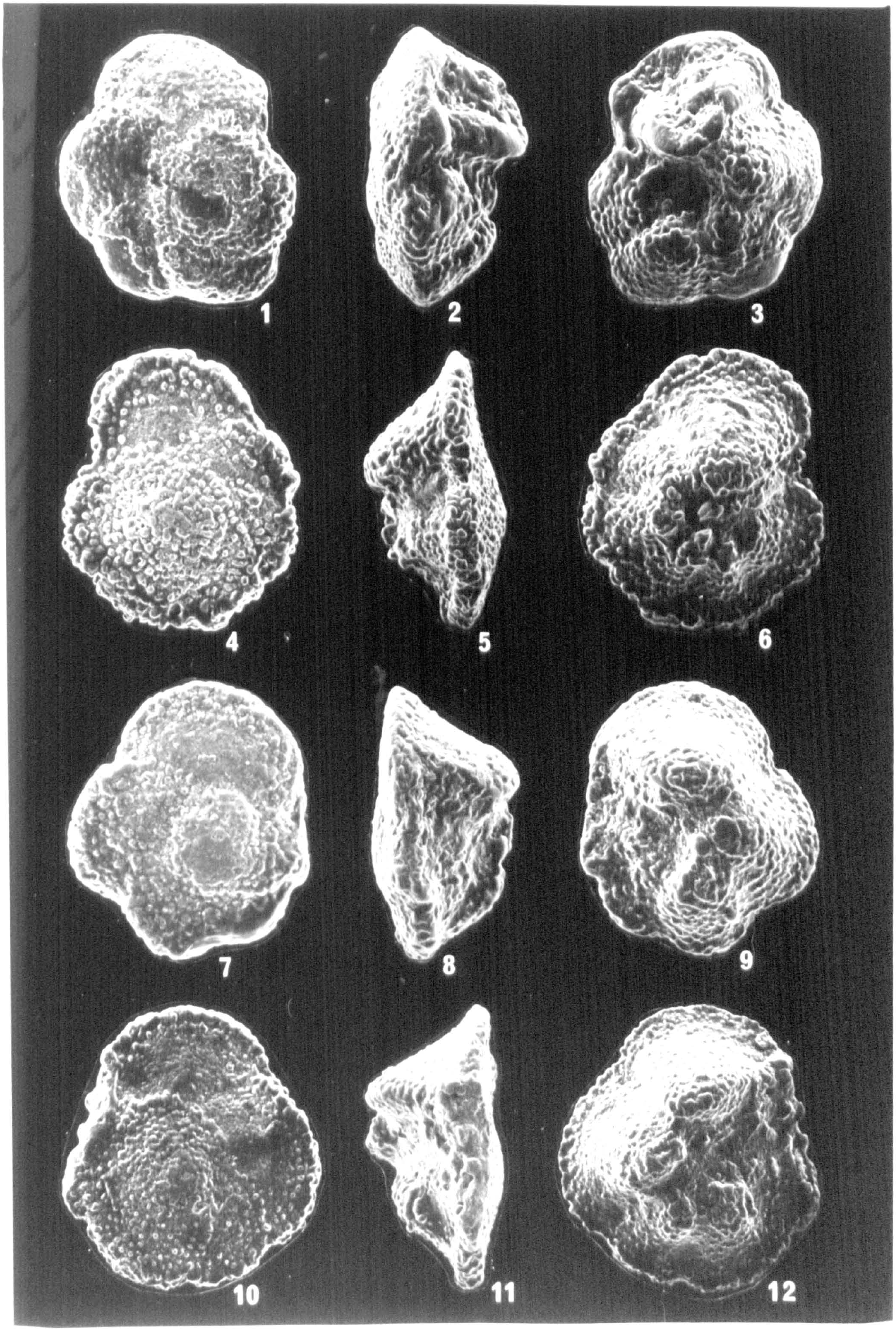
**Plate 5**

Figs. 1-3 *Morozovella formosa formosa* (Bolli, 1957). From sample WME 94,. Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x145. (See p. 99).

Figs. 4-6 *Morozovella gracilis* (Bolli, 1957). From sample WME 94, Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x150. (See p. 101).

Figs. 7-12 *Morozovella marginodentata* (Subbotina, 1953). From samples WME 86, WME 88 and WME 95, respectively. Both from the Wadi Musawa Section, Jabal Ja'alan area SE of Oman. Early Eocene. Two specimens in spiral, edge and umbilical view, respectively. Figs. 7-9, x175; 10-12, x130. (See p. 102).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## Plate 6

Figs. 1-3 *Morozovella marginodentata* (Subbotina, 1953). From sample WME 95, Wadi Musawa Section, Jabal Ja'alan area, SE Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x135. (See p. 102).

Figs. 4-6 *Morozovella nicoli* (Martin, 1943). From sample WM 1, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Palaeocene. Spiral, edge and umbilical views, respectively, x185. (See p. 104).

Figs. 7-9 *Morozovella occlusa* (Loeblich & Tappan, 1957). From sample WM 22, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Palaeocene. Spiral, edge and umbilical views, respectively, x130. (See p. 105).

Figs. 10-12 *Morozovella* sp cf. *M. parva.* From sample WM 22, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Palaeocene. Spiral, edge and umbilical views, respectively, x200. (See p. 107).

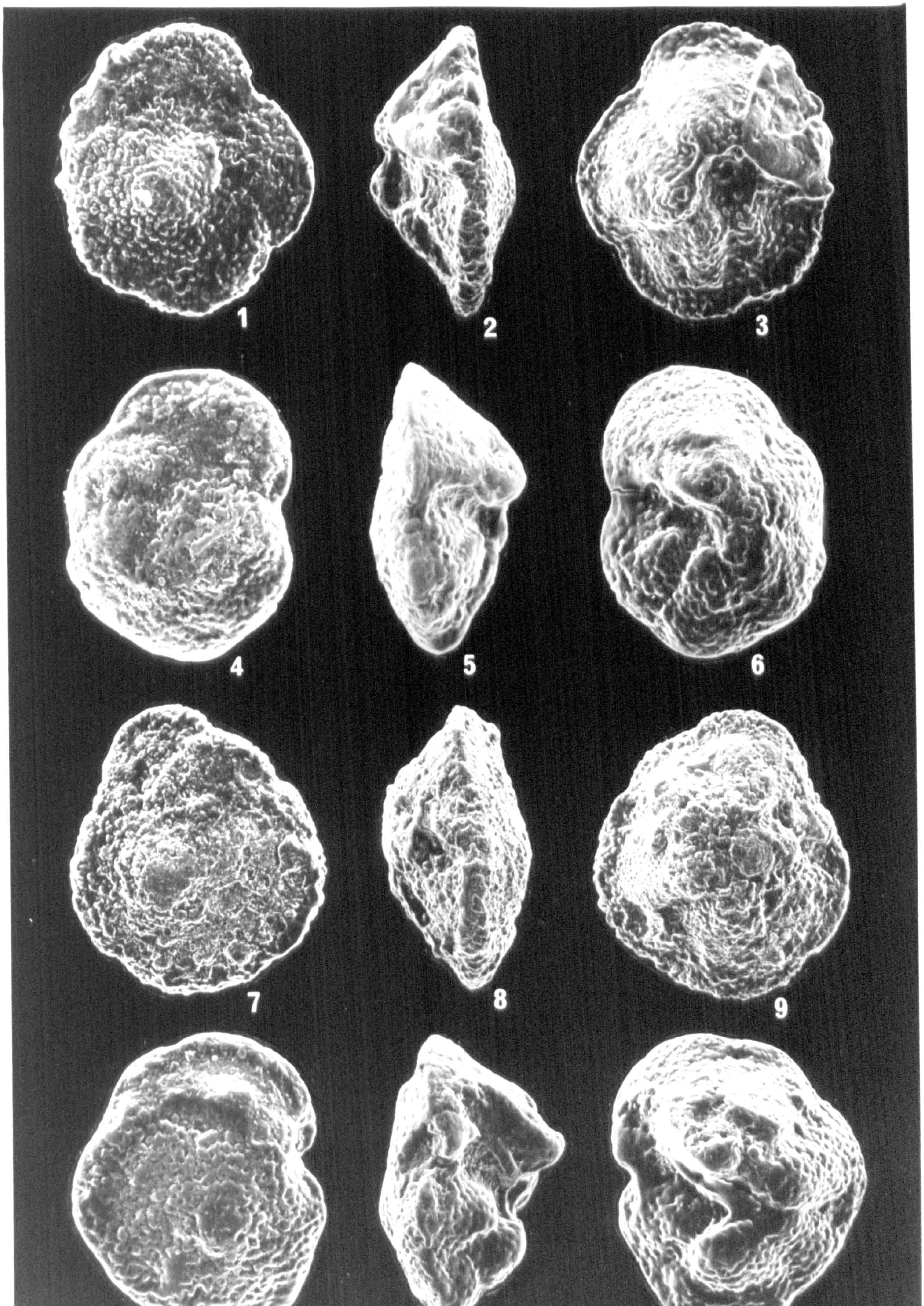
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**Plate 7**

Figs.1-3 *Morozovella* sp cf. *M. parva.* (Luterbacher, 1964). From sample WM 22, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Palaeocene. Spiral, edge and umbilical views, respectively, x135. (See p. 107).

Figs. 4-6 *Acarinina pentacamerata* (Subbotina, 1947). From sample WME 94, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x165. (See p. 122).

Figs. 7-9 *Morozovella pusilla mediterranica?* (El-Naggar, 1966). From sample WM 7, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Palaeocene. Spiral, edge and umbilical views, respectively, x120. (See p. 108).

Figs. 10-12 *Subbotina quadrata* (*sensu* El-Naggar, 1966). From sample WME 76 Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x240. (See p. 128).

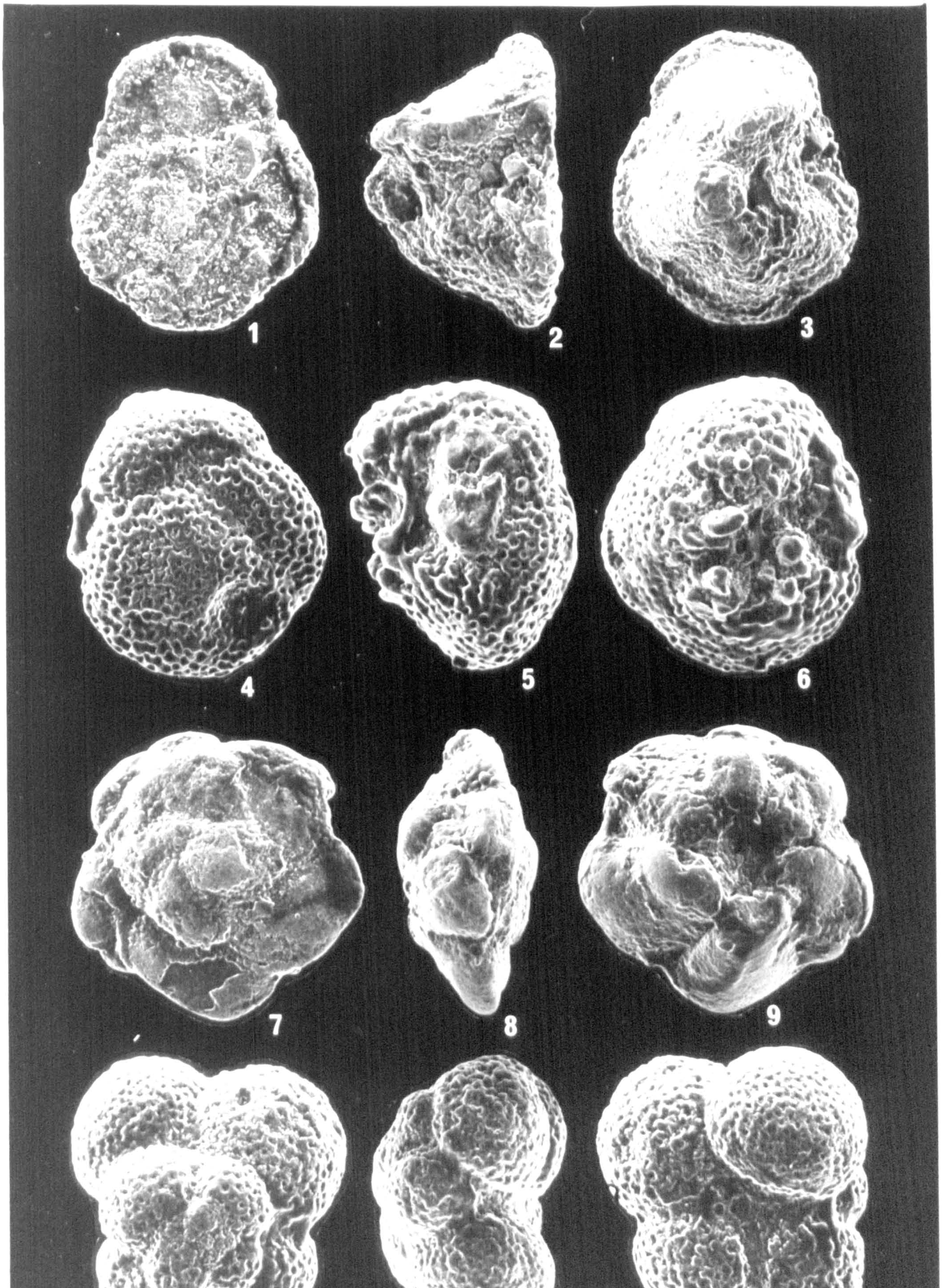
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**Plate 8**

Figs. 1-3 *Morozovella subbotinae* (Morozova, 1939). From sample WME 98 Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x150. (See p. 110).

Figs. 4-6 *Acarinina aspensis* (Bolli, 1957). From sample WM 35. Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge umbilical views, respectively, x140. (See p. 119).

Figs. 7-12 *Morozovella velascoensis* (Cushman, 1925). From samples WM 7 and WM 22, respectively. Both from the Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Palaeocene. Two specimens in spiral, edge and umbilical views, respectively. Figs. 7-9, x105; 10-12, x110. (See p. 111).

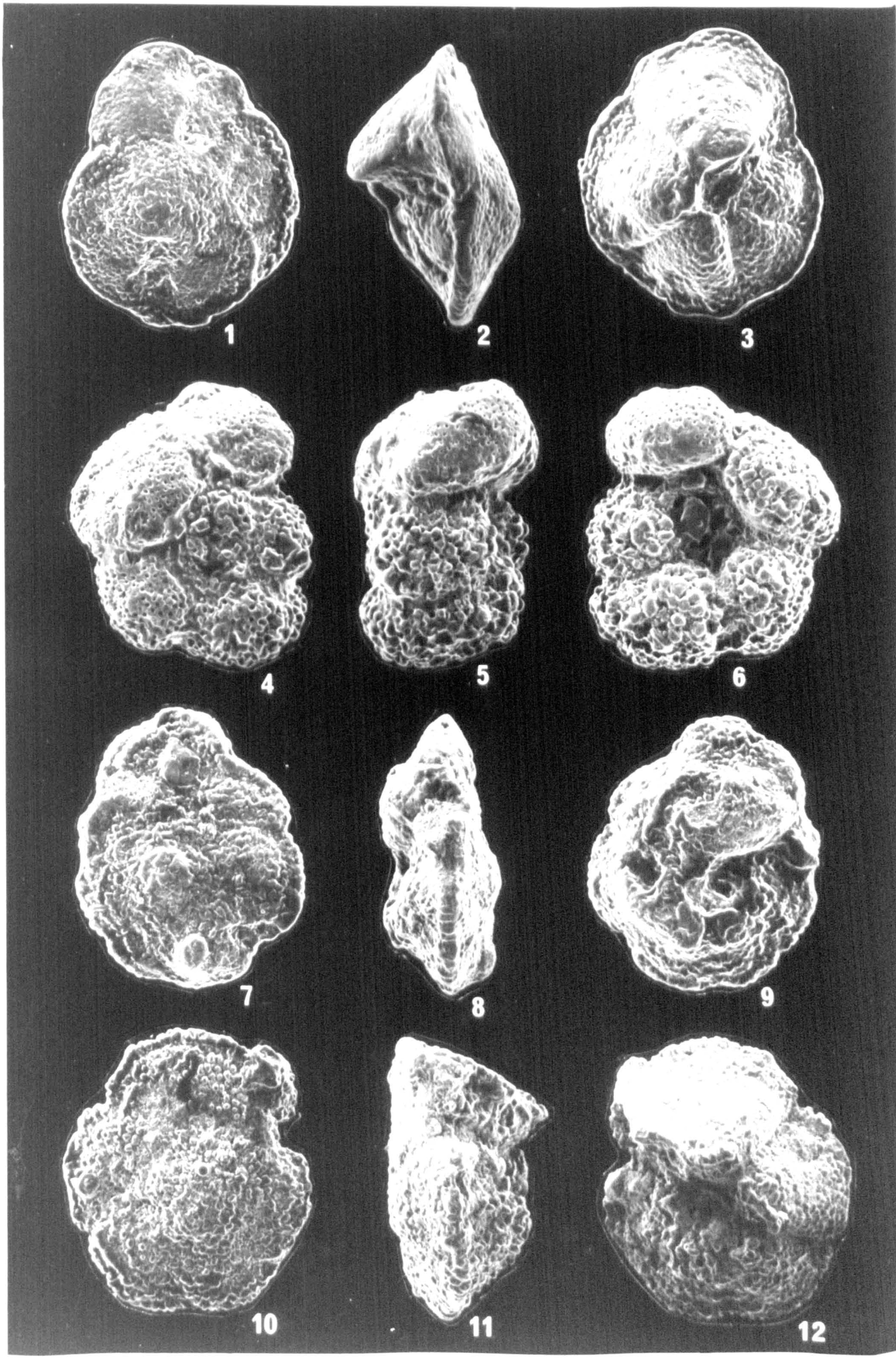
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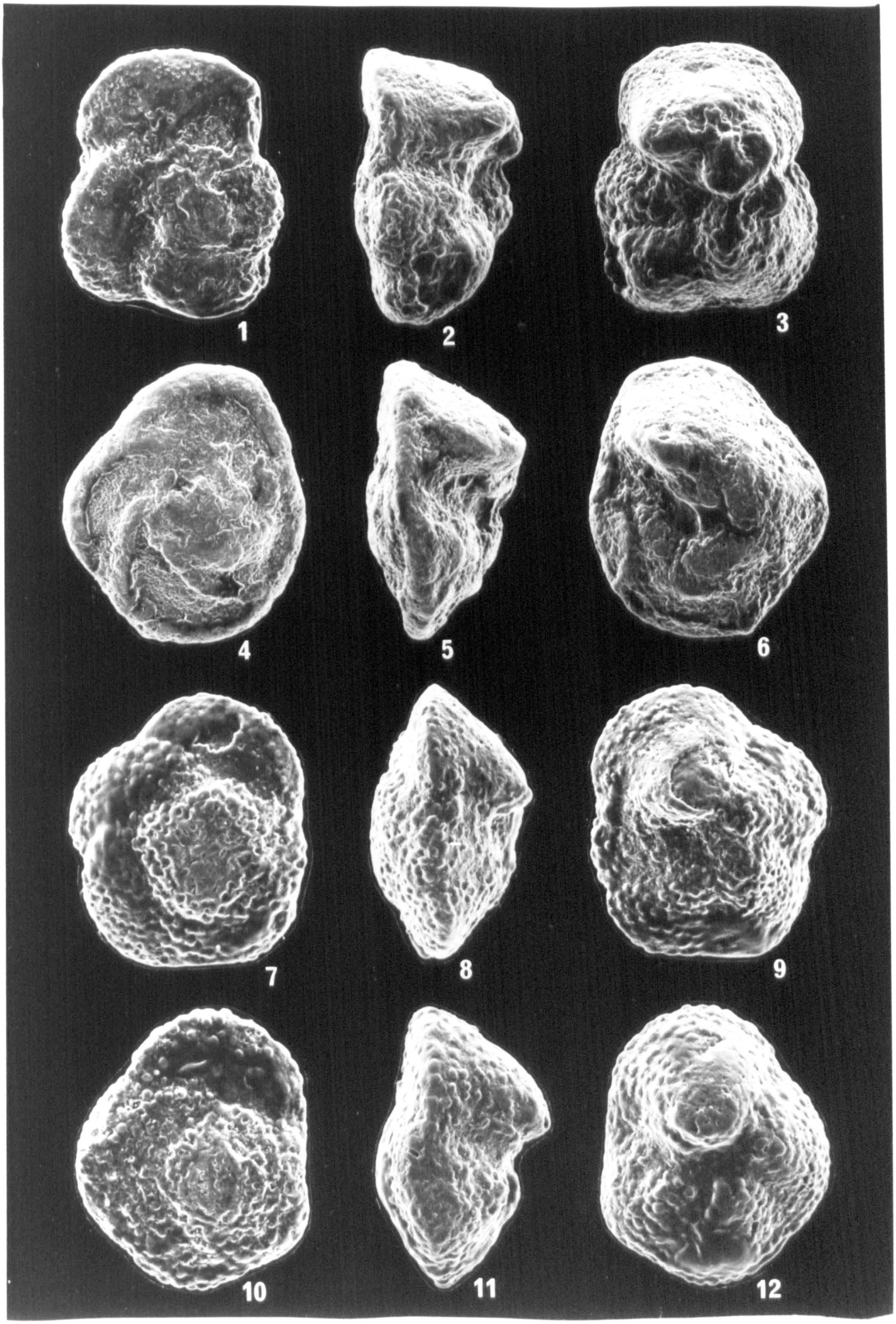
**Plate 9**

Figs. 1-3 *Morozovella* sp. A. From sample WME 94, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x110. (See p. 113).

Figs. 4-6 *Morozovella* sp. B. From sample WME 76, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x125. (See p. 114).

Figs. 7-12 *Morozovella* sp. C. From samples WME 98 and WME 103, respectively. Both from the Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Two specimens in spiral, edge and umbilical view, respectively Figs. 7-9, x245; 10-12, x230. (See p. 115).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## Plate 10

Figs. 1-3 *Morozovella* sp. D. From sample WME 182, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Middle Eocene. Spiral, edge and umbilical views, respectively, x150. (See p. 116).

Figs. 4-9 *Acarinina esnaensis* (Le Roy, 1953). Both from sample WM 35, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Two specimens in spiral, edge, and umbilical view, respectively. Figs. 4-6, x150; 7-9, x145. (See p. 121).

Figs. 10-12 *Acarinina soldadoensis* (Bronnimann, 1952b). From sample WM 35, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x165. (See p. 124).

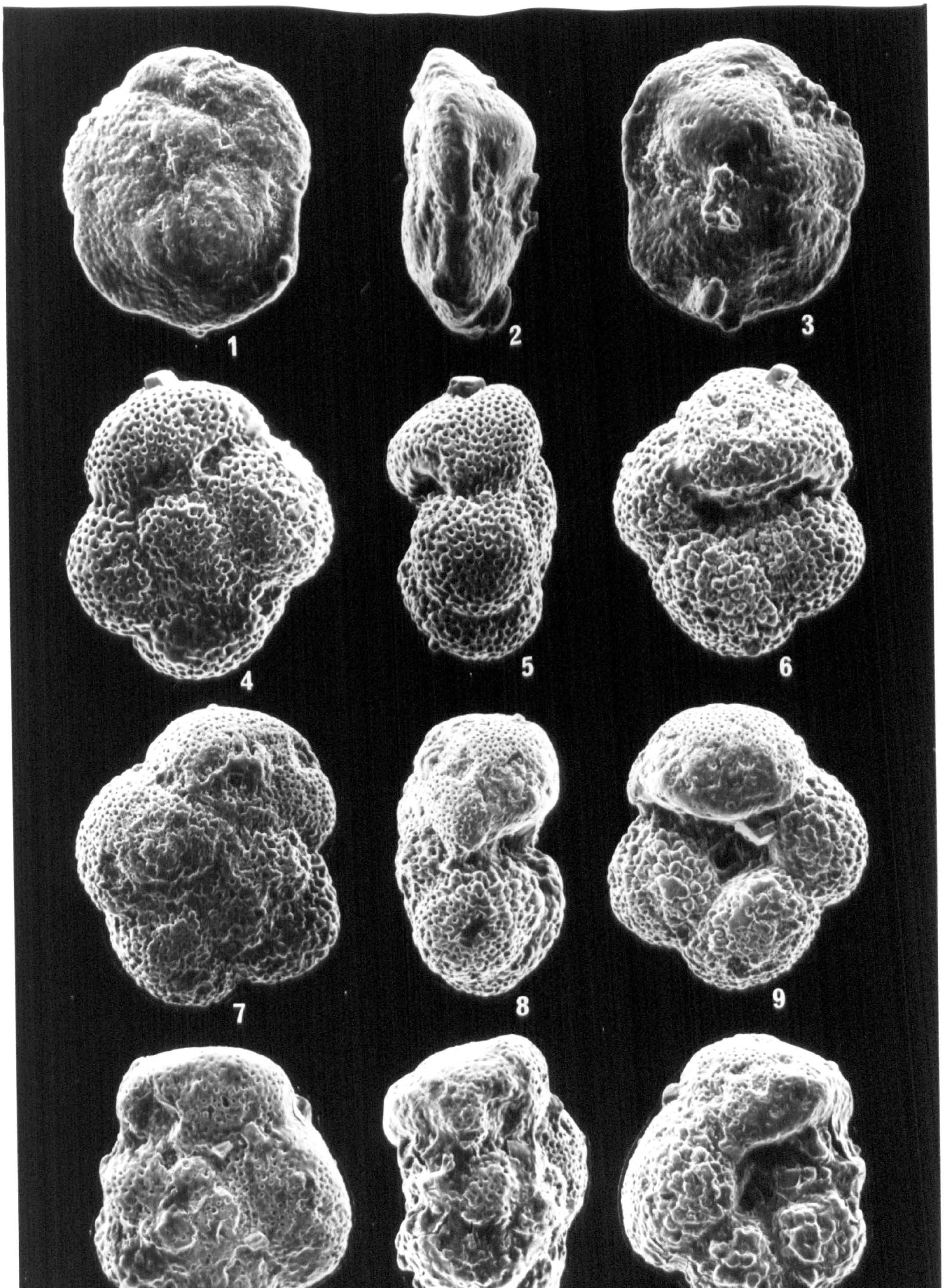
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**Plate 11**

Figs. 1-3 *Acarinina soldadoensis* (Bronnimann, 1952b). From sample WM 35 Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x150. (See p. 124).

Figs. 4-6 *Acarinina* sp. From sample WM 35, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x165. (See p. 125).

Figs. 7-9 *Subbotina triangularis* (White, 1928). From sample WM 7, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Palaeocene. Spiral, edge and umbilical views, respectively, x160. (See p. 130).

Fig. 10-12 *Subbotina triloculinoides* (Plummer, 1926). From sample WM 7, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Palaeocene. Spiral, edge and umbilical views, respectively, x140. (See p. 131).

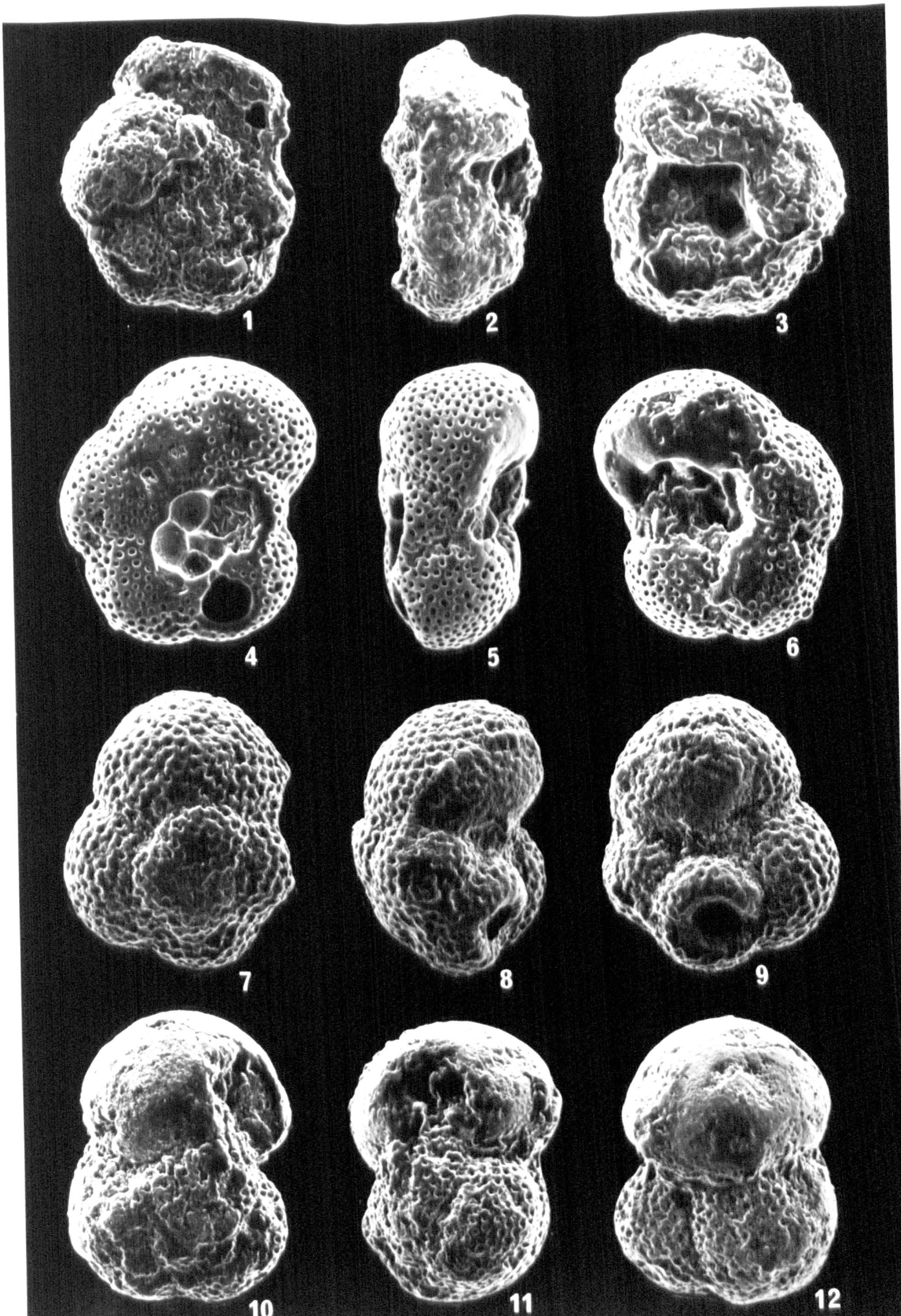
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**Plate 12**

Figs. 1-6 *Truncorotaloides libyaensis* (El-Khoudary,1977). From samples WME 186, and WME 205,respectively. Both from the Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Middle Eocene. Two specimens in spiral, edge and umbilical views, respectively. Figs.1-3, x170; 4-6, x195. (See p. 134).

Figs. 7-12 *Truncorotaloides topilensis* (Cushman, 1925a). From samples WME 147 and WME 148, respectively. Both from the Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Middle Eocene. Two specimens in spiral, edge and umbilical views, respectively. Figs. 7-9, 125; 10-12, x120. (See p. 136).

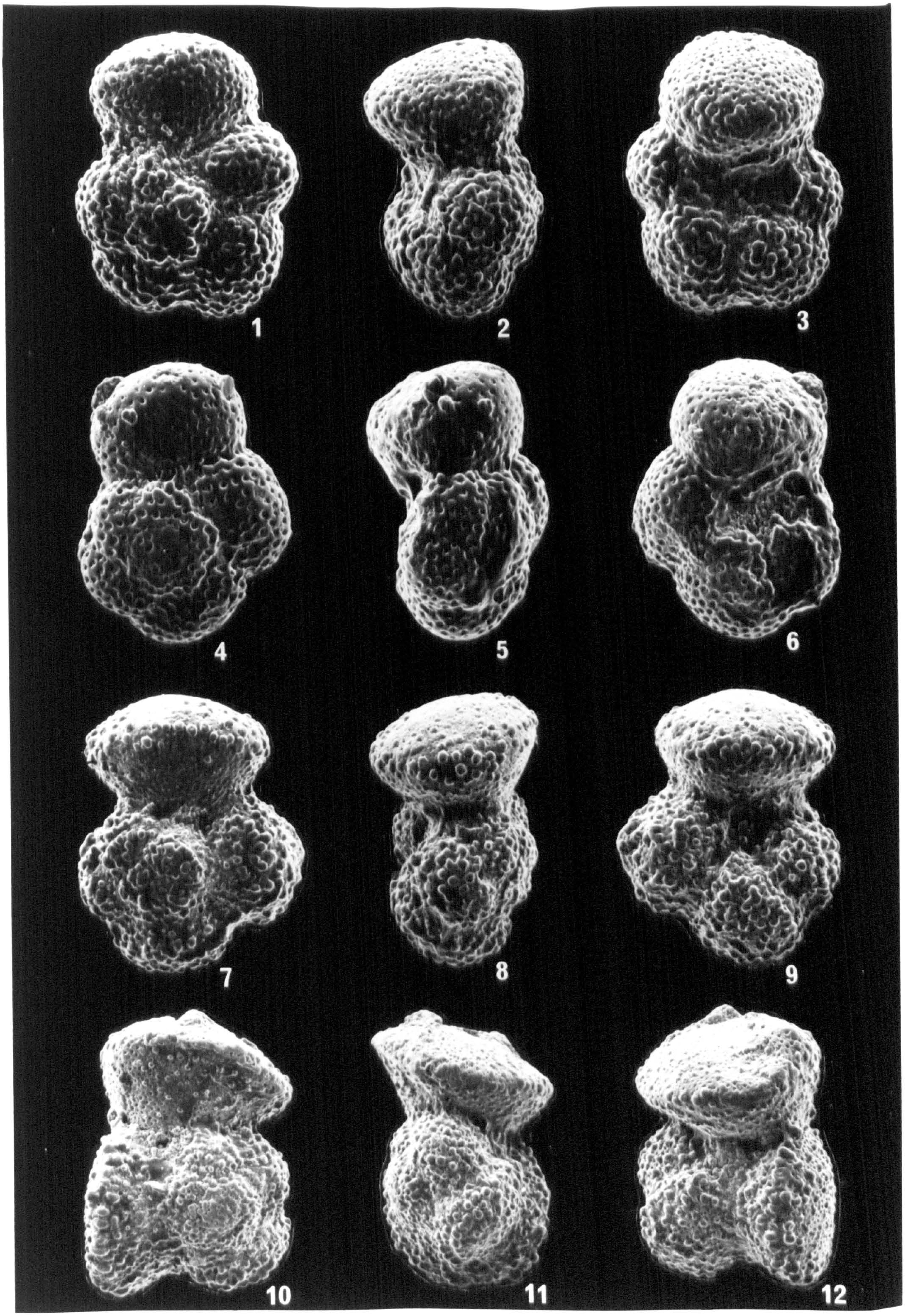
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**Plate 13**

Figs. 1-3 *Morozovella centralis* (Cushman & Bermudez, 1937). From sample WME 76, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge and umbilical views, respectively, x135. (See p. 95).

Figs. 4-6 *Turborotalia blowcentralis* nov. nov. (Blow, 1979). From sample WME 148, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Middle Eocene. Spiral, edge and umbilical views, respectively, x110. (See p. 139).

Figs. 7-12 *Hastigerina* sp. Both from sample WME 94. Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Two specimens in spiral, edge and umbilical view, respectively. Figs.7-9, x140; 10-12, x130. (See p. 143)


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**Plate 14**

Figs. 1-3 *Globigerinatheka barri* Bronnimman, 1952. From sample WME 183, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Middle Eocene. Spiral, and two side views showing bullae, respectively, x130. (See p. 146).

Figs. 4-6 *Globigerinatheka* cf. *curryi* Proto Decima & Bolli, 1970. From sample WM 186, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Middle Eocene. Spiral, and two side views showing bullae, respectively, x135 (See p. 148).

Figs. 7-8 *Globigerinatheka euganea* (Beckmann, 1953). From sample WME 148, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Middle Eocene. Spiral, and side views showing bullae, respectively, x115. (See p. 149).

Figs. 9-10 *Globigerinatheka subconglobata subconglobata* Shutskaya, 1958. From sample WME 76, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral and side views showing bullae, respectively, x120. (See p. 150).

Figs. 11-12 *Globigerinatheka* sp. A. From sample WME 183, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Middle Eocene. Spiral and side views showing bullae, respectively, x 120. (See p. 151).

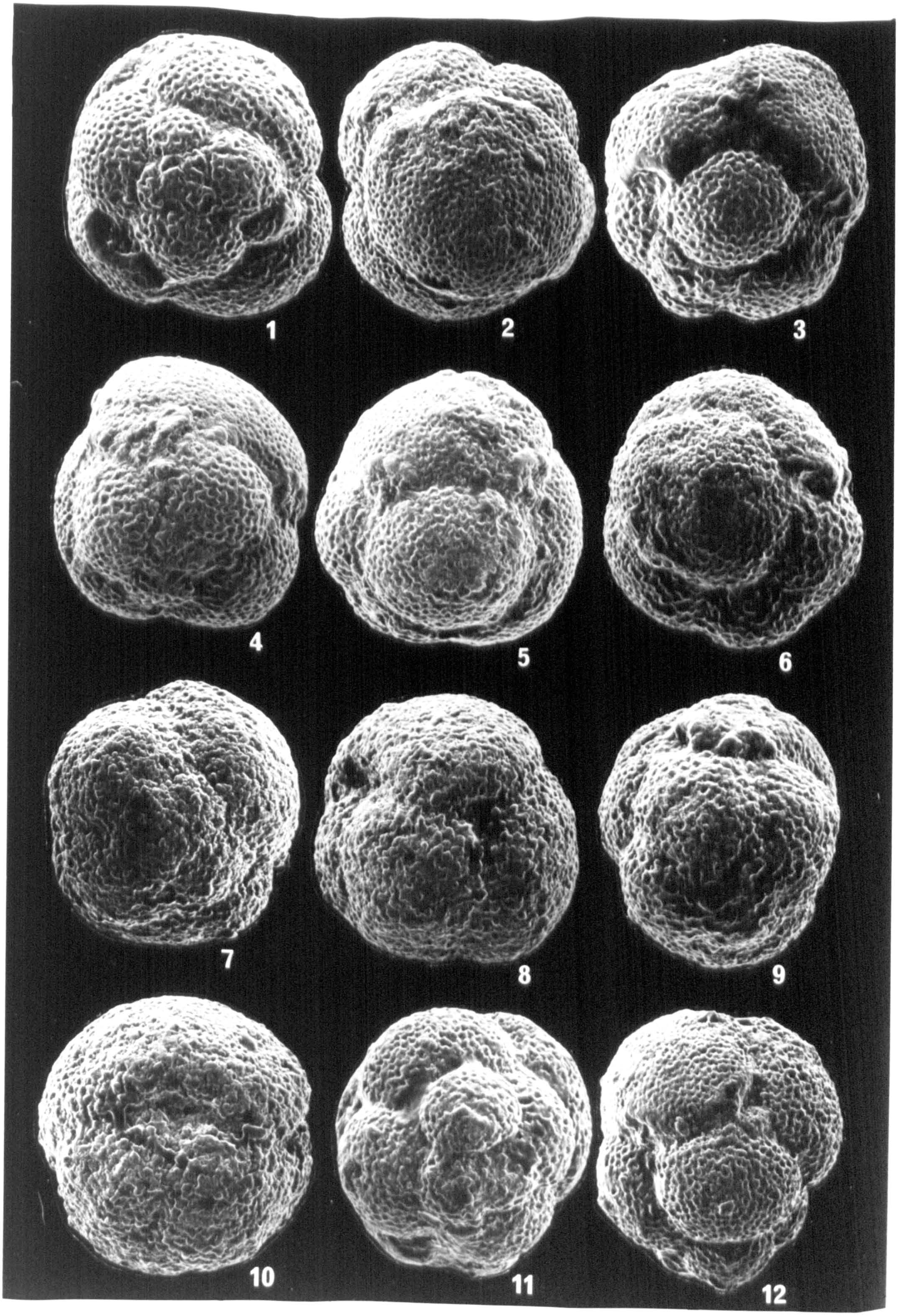
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**Plate 15**

Figs. 1-2 *Globigerinatheka* sp. B. From sample WME 186, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Middle Eocene. Two side views showing bullae, x120. (See p. 152).

Figs. 3-5 *Morozovella angulata* (White, 1928). From sample WM 7. Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Palaeocene. Spiral, edge and umbilical views, respectively, x120. (See p. 89).

Figs. 6-8 *Morozovella aragonensis* (Nuttall, 1930). From sample WM 35, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Early Eocene. Spiral, edge umbilical views, respectively, x95. (See p. 90).

Figs. 9-11 *Globigerina linaperta* group. From sample, Wadi Musawa Section, Jabal Ja'alan area, SE of Oman. Late Eocene. Spiral, edge and umbilical views, respectively, x100. (See Chapter Seven).

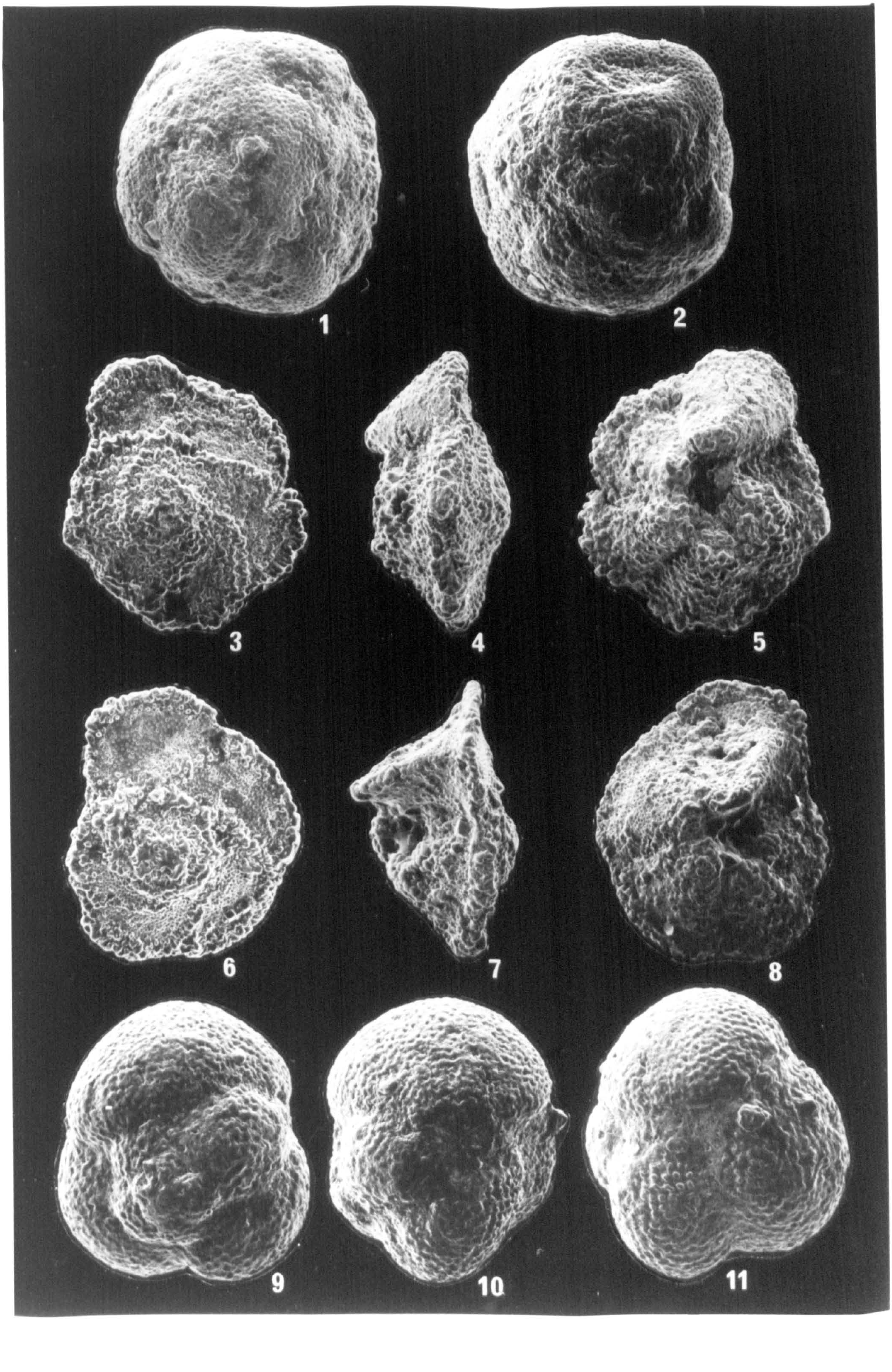
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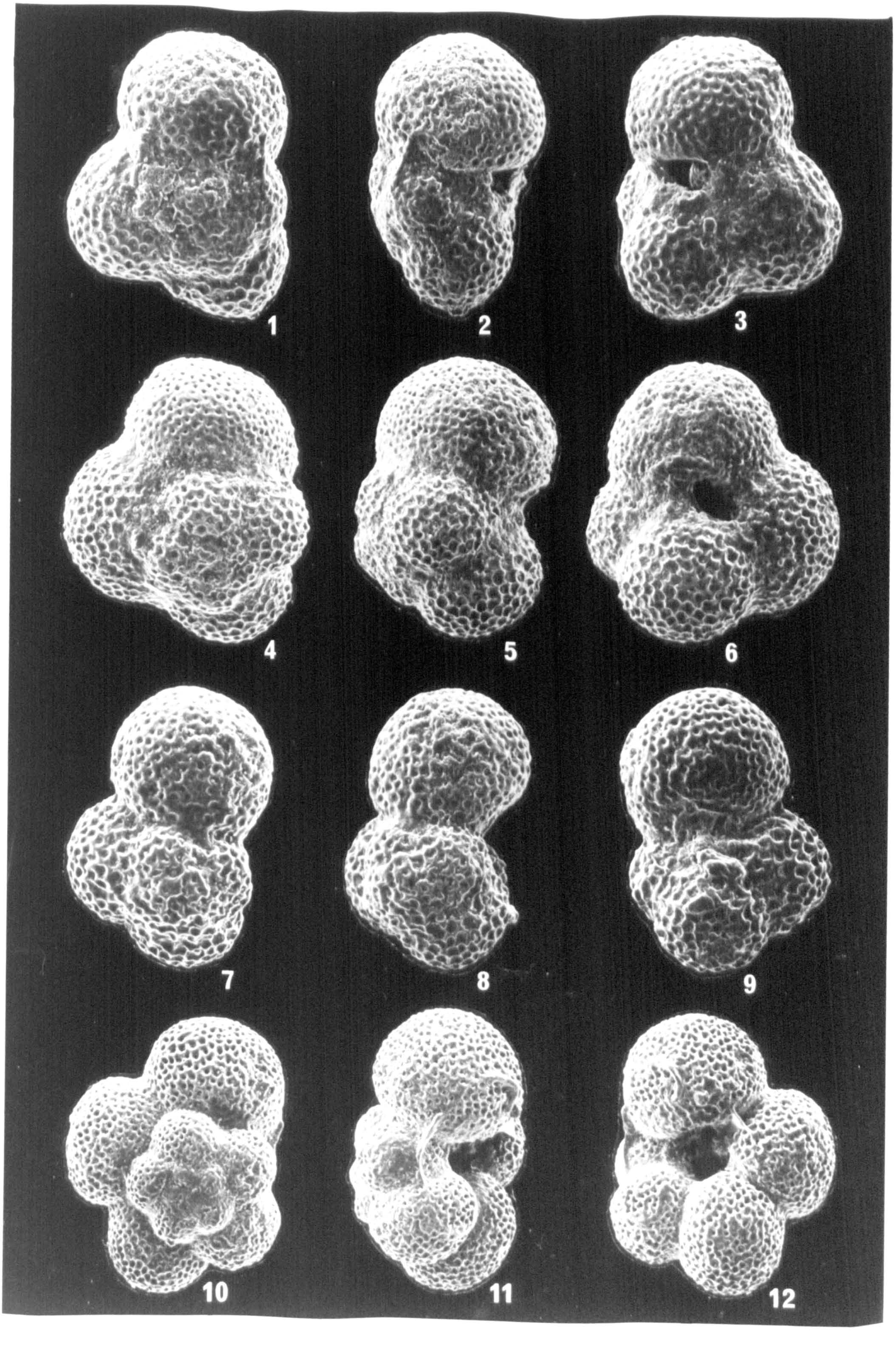
**Plate 16**

Figs 1-12 *Globigerina linaperta* group (*sensu* Stainforth *et al.*, 1975).

Three specimens from samples WME229, 231, 236, Wadi Musawa section and one from sample WS97, Wadi Suq section, SE Oman. Spiral, edge and umbilical view, respectively. Figs. 1-3 x200; 4-6, 175; 7-9, x190; 10-12. x180.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## Plate 17

Figs. 1-6 *Globigerina linaperta* group (*sensu* Stainforth *et al.*, 1975). From samples WS97 and WS106, Wadi Suq section SE Oman. Two specimens in spiral, edge and umbilical view, respectively. Figs. 1-3, x125; 4-6, x130.

Figs. 7-12 Reworked Cretaceous planktonic foraminifera from base of Wadi Musawa Section, Jabal Ja'alan area, SE Oman.

Fig. 7 *Heterohelix labellosa* . Side view, x230.

Fig. 8 *Trinitella scotti* Bronnimann. Spiral view, x140.

Fig. 9 *Globotruncana mariei* Banner & Blow. Umbilical view, x170.

Fig. 10 *Rugoglobigerina rugosa* (Plummer). Umbilical view, x200.

Fig. 11 *Planohedbergella voluta* Umbilical view, x180.

Fig. 12 *Globotruncana rosetta* (Carsey). Umbilical view, x150.

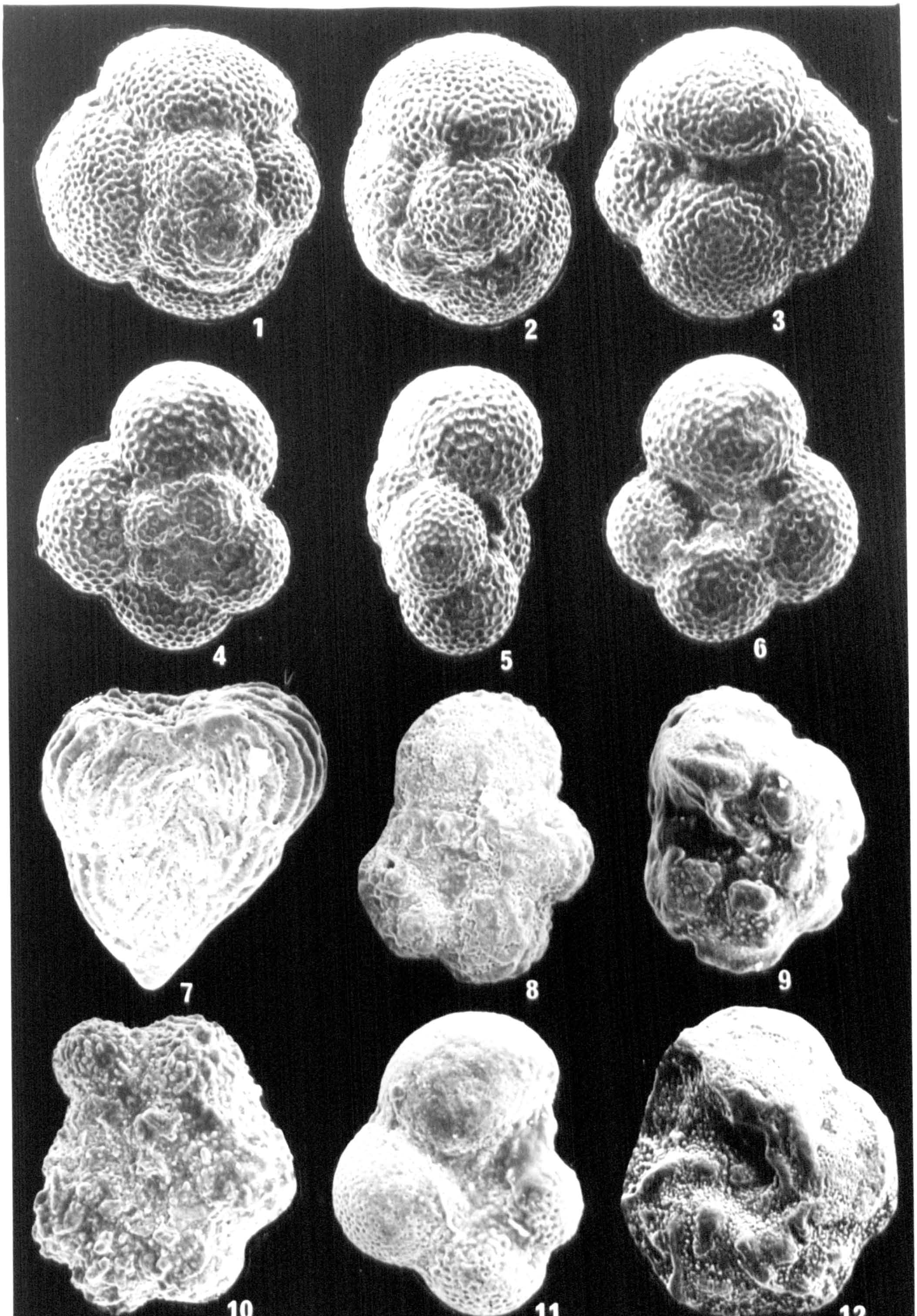
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**Plate 18**

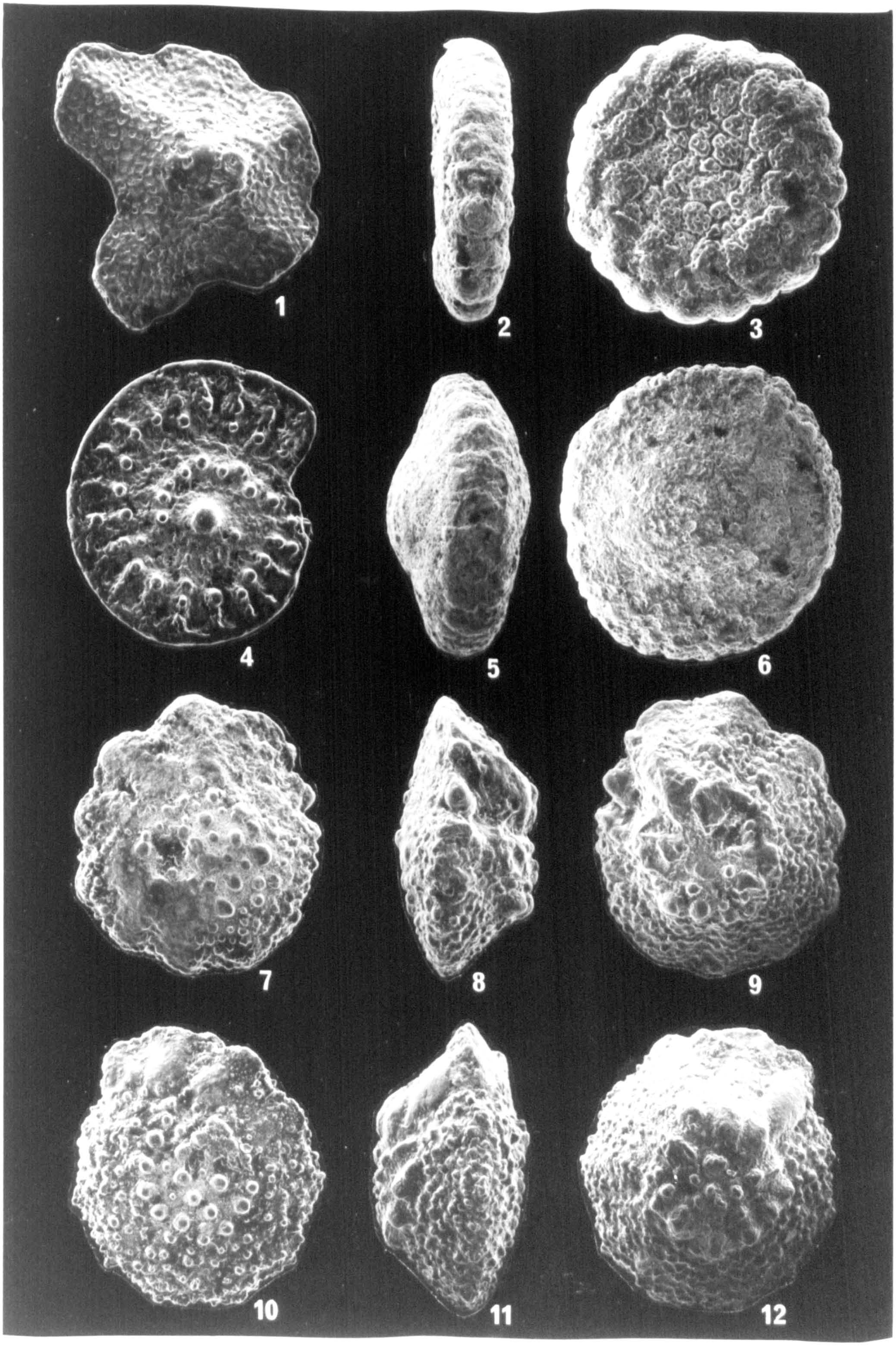
Fig. 1 *Asterocyclina* sp. B. From sample WM 35. Wadi Musawa section, Jabal Ja'alan area, SE Oman. Early Eocene. External view, x30. (See p. 174).

Figs 2-3 *Linderina* sp. A. From sample WME 184, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Edge and side views, respectively, x50. (See p. 172).

Fig. 4 *Operculina musawaensis* nov. sp. Holotype (A-form). From sample WM 35 Wadi Musawa section, Jabal Ja'alan area, SE Oman. Early Eocene. Side view, x30. (See p. 166).

Figs. 5-6 *Linderina* sp B. From sample WME 148, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Edge and side views, respectively, x20. (See p. 172).

Figs. 7-12 *Neorotalia omanensis* nov. sp. From samples WME 148 and WME 184, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. in spiral, edge and umbilical view, respectively, x65. Figs. 10-12 Holotype Figs. 7-9 Paratype (See p. 183).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## Plate 19

Figs. 1-2 *Nummulites honogoensis* (Hanzawa, 1964). From sample WM31a, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Basal of Early Eocene. 1- Equatorial section of B-form, x30. 2- Axial section of A-form, x20. (See p. 162).

Fig. 3. *Nummulites atacicus* (Leymerie, 1846). From sample WME 94, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Early Eocene. Axial section of B-form x30. (See p. 157).

Fig. 4 *Alveolina drobneae* (White, 1989). From sample WM 34, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Early Eocene. Axial section of A-form, x30. (See p. 180).

Fig. 5. *Astereocyclina* sp. B. From sample WM 35, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Early Eocene. Equatorial section of A-form, x40. (See p. 174).

Fig. 6 *Neorotalia omanenesis* sp. nov. From sample WME 148, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Axial section, x115. (See p. 183).

Fig. 7 *Lepidocyclina* (*Eulepidina*) sp. From sample WS106, Wadi Suq, Jabal Ja'alan area, SE Oman. Early-mid-Oligocene. Axial section of A-form, x15. (See p. 178).

Fig. 8 *Nummulites fichteli* (Michelotti, 1841). From sample WS106, Wadi Suq section, Jabal Ja'alan area, SE Oman. Early-mid-Oligocene. Axial section of A-form, x15. (See p. 159).

Fig. 9 *Discocyclina* sp. aff. *javana* (Verbeek, 1892). From sample WME 238, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Axial section of A-form, x30. (See p. 176).

Fig.10 *Miscellanea primitiva* ((Hofker, 1959). From sample WM 9, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Palaeocene. Axial section, x30. (See p. 168).

Fig. 11 *Discocyclina* sp. cf. *D. dispensa* (Sowerby, 1840). From sample WME 190, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Axial section of A-form, x14. (See p. 175).


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**Plate 20**

Fig. 1 *Nummulites globulus* (Leymerie, 1846). From sample WM 34, Wadi Musawa section, SE Oman Early Eocene. Axial section, A-form, x55. (See p. 161).

Figs. 2-3 *Nummulites maculatus* (Nuttall, 1926). From sample WME 190, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Two A-forms specimens in axial section, x35. (See p. 163).

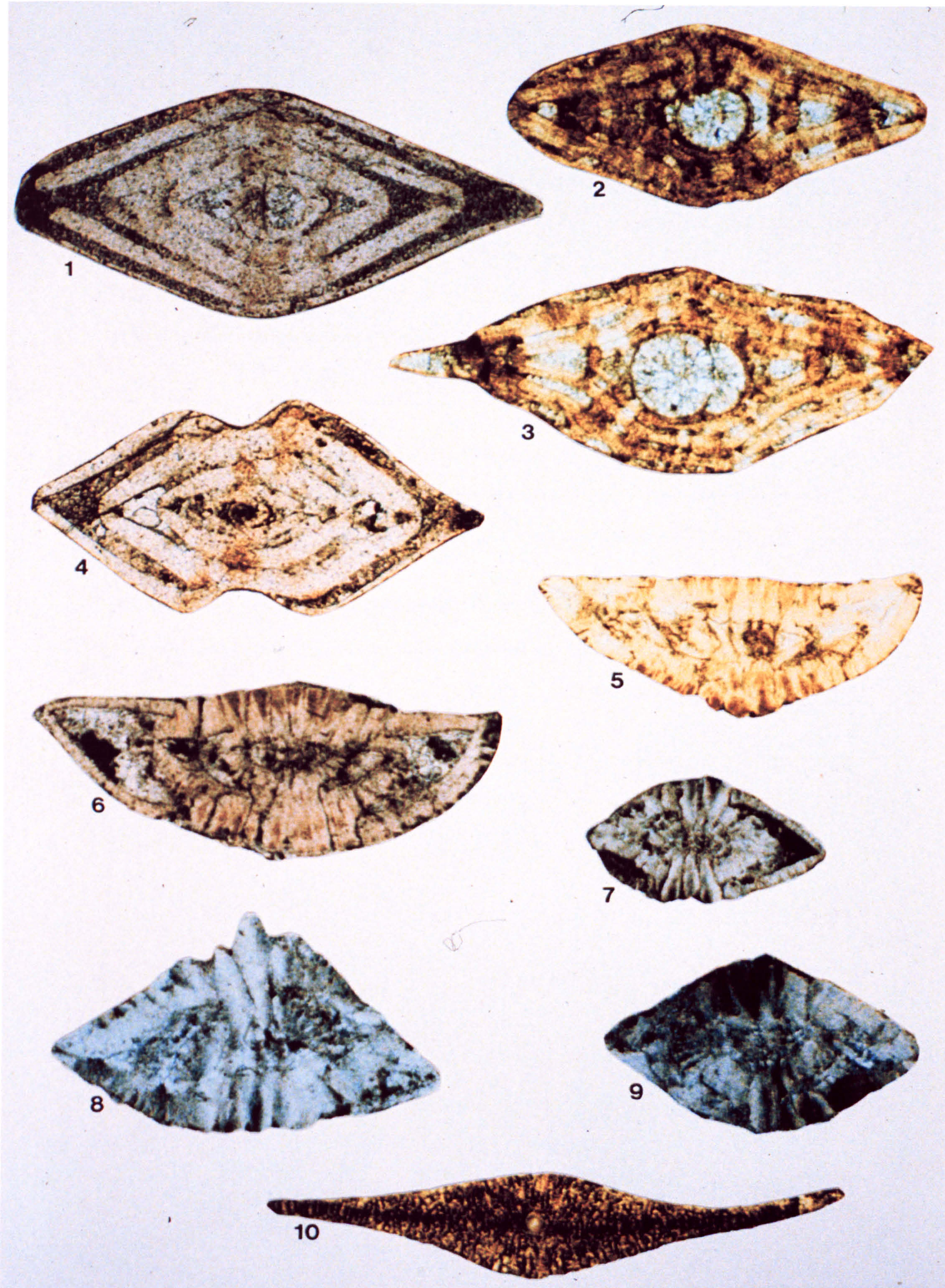
Fig. 4 *Nummulites fossulata* (de Cizancourt, 1938). From sample WM43, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Early Eocene. Axial section, x50. (See p. 160).

Figs. 5-6 *Daviesina iranica* (Rahaghi, 1983). Sample WM11 & WM16. Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Palaeocene. Two axial sections, x35. (See p. 169).

Fig. 7- *Daviesina shirazensis* (Rahaghi, 1983). From sample WM9, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Palaeocene. Axial section, x40. (See p. 170).

Figs 8-9. *Miscellanea primitiva* (Hofker, 1959). From samples WMC 17 and WMC 18, respectively Wadi Musawa section, Jabal Ja'alan area, SE Oman.. Late Palaeocene. Two specimens in axial sections, x35; x40, respectively. (See p. 168).

Fig.10 *Asterocyclina* sp. A. From sample WMC16, Wadi Musawa section, Jabal Ja'alan area, SE Oman.. Late Palaeocene. Axial section, x40. (See p. 173).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## Plate 21

Figs. 1-4 *Linderina* sp. A. From samples WME 181 and WME 183, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. 1-2, Equatorial sections, x55 and x50, respectively; 3-4, Axial sections, x60 and x45, respectively. (See p. 172).

Fig. 5 *Linderina* sp. B. From sample WME182, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Axial section, x40. (See p. 172).

Figs. 6-7 *Lepidocyclina* (*Nepherolepidina*) sp. From sample WS97, Wadi Suq, Jabal Ja'alan area, SE Oman. Early mid-Oligocene. Axial and equatorial sections, x35 and x45, respectively. (See p. 177).

Figs. 8-9 Incertae sedis. From sample WME 148, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Equatorial and axial sections, x55 and x70, respectively. (See p 184).


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**Plate 22**

Fig. 1- *Nummulites discorbinus* (Schlotheim, 1820). From sample WME 148, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Axial section x20. (See p.158).

Fig. 2- *Nummulites striatus* (Bruguiere, 1792). From sample 236, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Eocene. Equatorial section, x10. (See p. 165).

Fig. 3- *Gypsina* sp. From sample WME 227, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Eocene. Equatorial section, x40. (See p. 182).

Figs. 4-5 *Neorotalia omanensis* nov. sp. paratypes from sample WME148, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Equatorial and axial sections, x50 and x55. (See p. 183).

Fig. 6 *Gypsina globulus* (Reuss, 1848). From sample WME 186, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene, Equatorial section, x40. (See p. 181).

Figs. 7-9 *Operculina musawaensis* nov. sp. paratypes A-forms from sample WM 35, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Early Eocene. Oblique, axial and equatorial sections, respectively, all x30. (See p. 166)

Figs. 10-11 *Dictyoconus egyptiensis* (Chapman, 1900). From sample WME 98, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Early Eocene. Axial and equatorial sections, x30 and x25, respectively. (See p. 178).

Fig. 12 *Coskinolina balsillei* (Davies, 1930). From sample WME 111, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Early Eocene. Axial section, x20. (See p. 179).

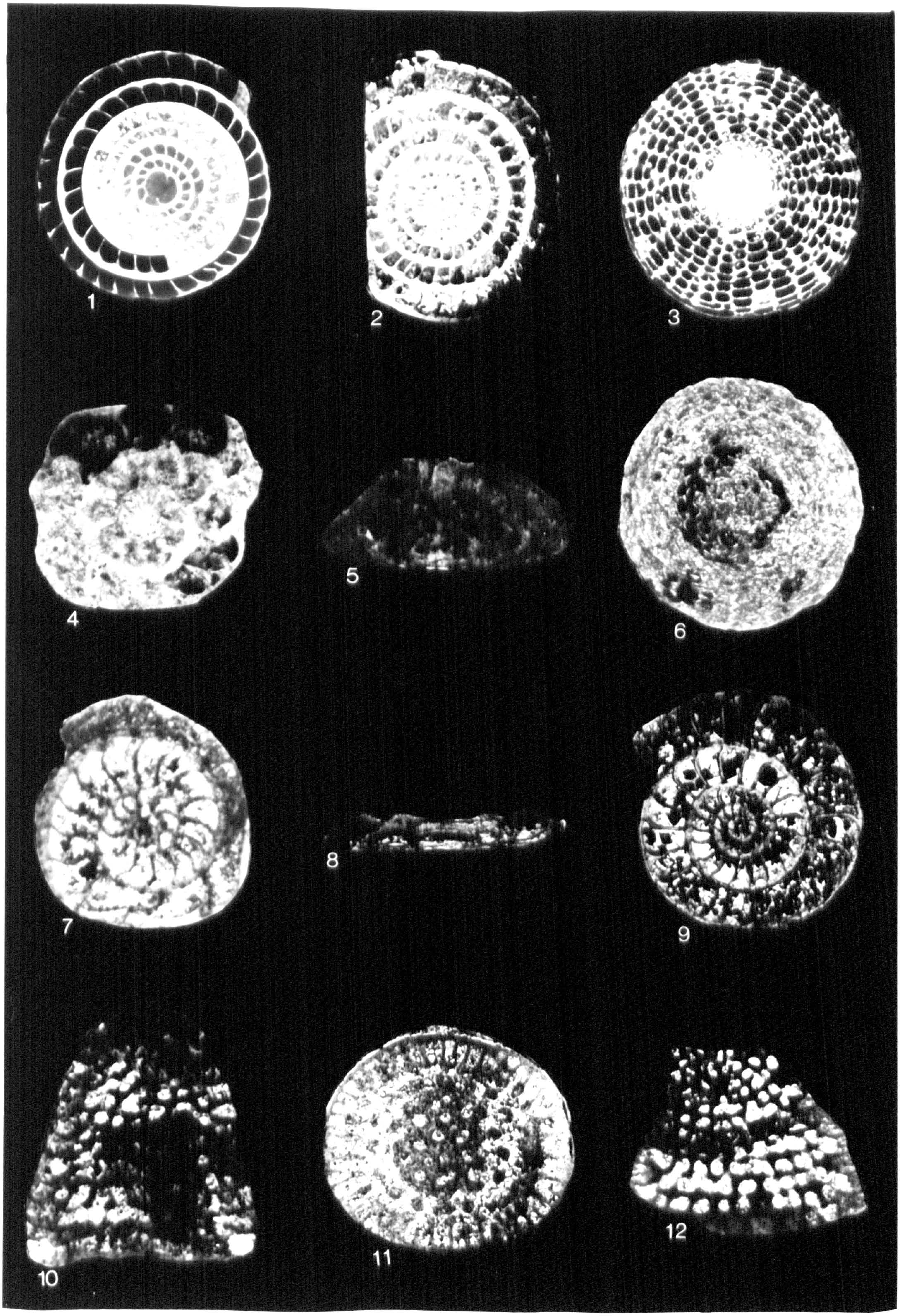
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**Plate 23**

Figs. 1-4 *Nummulites striatus* (Bruguiere, 1792). From samples WME 233 and WME 236, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Eocene. Axial sections, x20, x20, x15, and x15, respectively. (See p. 165).

Fig. 5 *Nummulites schaubi* (Racey, 1992). From sample WME 197, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Axial section, x15. (See p. 164).

Figs. 6-8 Incertae sedis. From sample WME 148, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. Three views of same specimen, x65. (See p. 184).

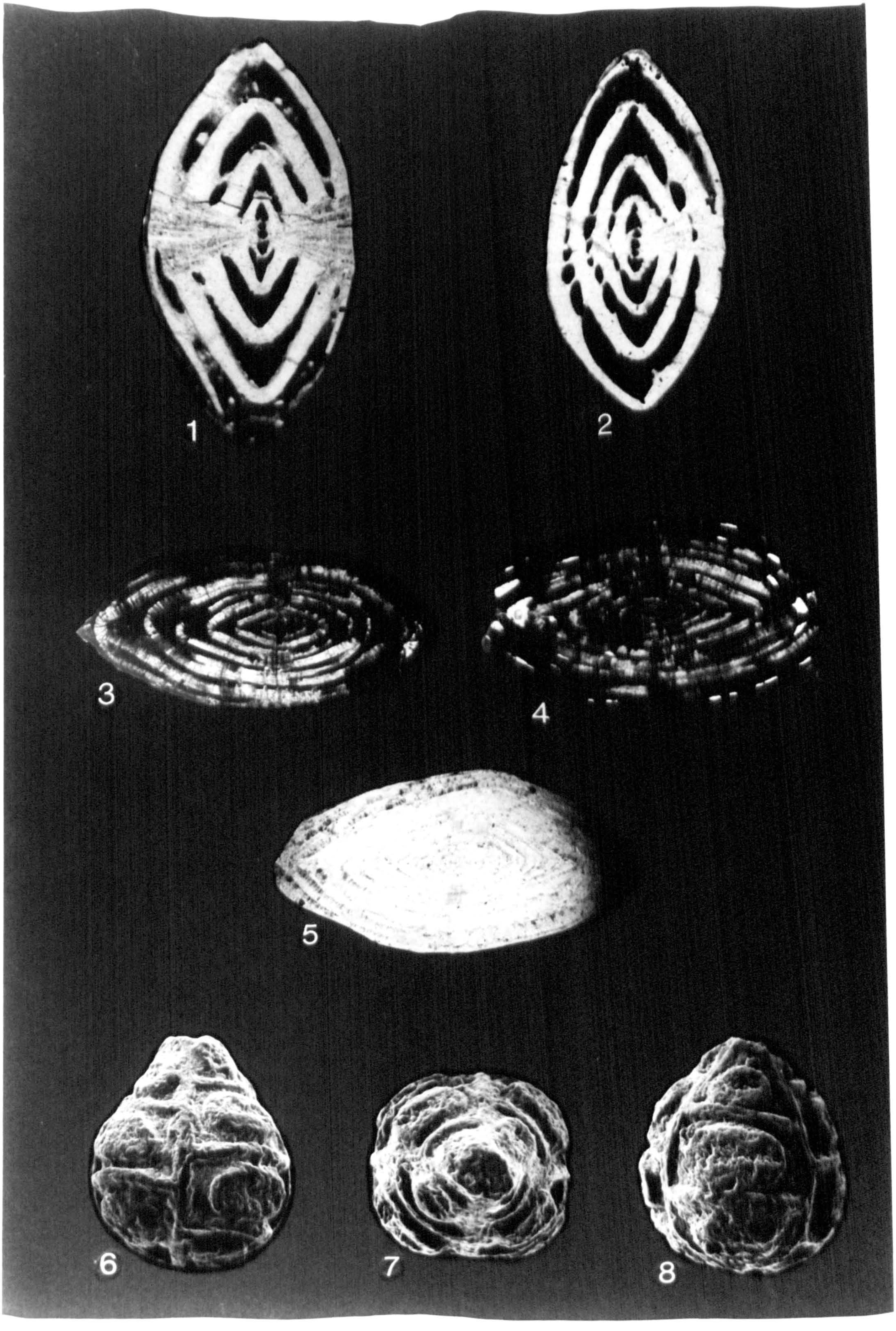
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**Plate24**

**Corals and molluscs**

[*The presence of corals and molluscs within the Wadi Musawa Section particularly the Musawa Formation suggest that the salinity was not far from normal, although they could be washed of fragments and these two rounded corals may lived on soft substrate in rather quiet protected or slightly deeper water but definitely within the photic zone. However, the molluscs suggest a low intertidal to subtidal environment*]

Figs. 1-2 Two views of compound "button" coral. From sample above campsite, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Eocene. x15.

Fig. 3 *Nucula* sp. From grey limestone sample, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. x1.

Fig. 4 *Corbula* sp. From sample WME 205, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. x2.

Fig. 5 *Bicorbula* sp. From sample WME 205, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. x1.5.

Fig. 6 B*icorbula* sp. From sample WME 206, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. x1.5.

Fig. 7 Lucinid from sample WME 206, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. x1.

Fig. 8 *Natica* sp. From sample WME 203, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Middle Eocene. x1.

Fig. 9 *Bicorbula* sp. From sample WME 206, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Middle Eocene. x1.5.

Fig. 10 *Turritella* sp. From Wadi Musawa section, Jabal Ja'alan area, SE Oman. Late Eocene. x2.

Fig. 11 *Turritella* sp. From sample WME 205, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. x0.5

Fig. 12 *Turritella* sp. From sample WME 206, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. x1.

Fig. 13 *Turritella* sp. From sample WME 206, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Upper Middle Eocene. x1.

Fig. 14 *Turritella* sp From sample WME 205, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. x1.

Fig. 15 *Natica* sp. From sample WME 205, Wadi Musawa section, Jabal Ja'alan area, SE Oman. Middle Eocene. x1.


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# *Appendix*

# Appendix 1
## Methodology

| | | | | | | Number of Specimens | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample No** | **Lithology** | **Thin Section** | **Photo** | **Processed** | **SEM** | **Planktonic** | **Small benthic** | **Larger foram** | **Ostracods** | **Radiolaria** | **Charophytes** | **Macro** |
| WM1 | Shale | x | | Yes | ✓ | 25 | 69 | | 1 | | | |
| WM2 | Wst /Mst | ✓ | Taken | Yes | | | | | | | | |
| WM3 | Wackestone | ✓ | Taken | Yes | | | | | | | | |
| WM4 | Wackestone | ✓ | Taken | | | | | | | | | |
| WM5 | Wackestone | ✓ | Taken | | | | | | | | | |
| WM6 | Wackestone | ✓ | Taken | Yes | | | | | | | | |
| WM7 | Shale | x | | Yes | ✓ | 48 | 55 | | 3 | 2 | | |
| WM8 | Packstone | ✓ | Taken | Yes | | | | | | | | |
| WM9 | Grainstine | ✓ | Taken | Yes | | | | | | | | |
| WM10 | Wst /Pst | ✓ | Taken | | | | | | | | | |
| WM11 | Wackestone | ✓ | Taken | | | | | | | | | |
| WM12 | Wackestone | ✓ | Taken | | | | | | | | | |
| WM13 | Packstone | ✓ | Taken | Yes | | | | | | | | |
| WM14 | Wackestone | ✓ | Taken | Yes | | | | | | | | |
| WMC12 | Calcrudite | | | | | | | | | | | |
| MWC13 | Calcarenite | | | | | | | | | | | |
| WMC14 | Calclutite | | | | | | | | | | | |
| WMC15 | Calcrudite | ✓ | Taken | | | | | | | | | |
| WMC16 | Calcarenite | ✓ | Taken | | | | | | | | | |
| WMC17 | Calclutite | ✓ | Taken | | | | | | | | | |
| WMC18 | Calcrudite | ✓ | Taken | | | | | | | | | |
| WMC19 | Calcarenite | ✓ | Taken | | | | | | | | | |
| WMC20 | Calclutite | ✓ | Taken | Yes | | | | | | | | |
| WM21 | Wackestone | ✓ | Taken | Yes | | | | | | | | |
| WM22 | Shale | x | | Yes | ✓ | 33 | 5 | | 10 | | | |
| WM23 | Wackestone | ✓ | Taken | Yes | | | | | | | | |
| WM24 | Shale | x | | Yes | | | | | 8 | | | |
| WM25 | Shale | ✓ | Taken | | | | | | | | | |
| WM26 | Shale | | | Yes | | | | | 2 | | | |
| WM27 | Shale | ✓ | Taken | | | | | | | | | |
| WM28 | Shale | ✓ | Taken | | | | | | | | | |
| WM29 | Packstone | ✓ | Taken | Yes | ✓ | | | | | | | |
| WM30 | Pst /Wst | ✓ | Taken | Yes | | | | | | | | |
| MW31a | Shale | | | | ✓ | | | | | | | |
| WM31b | Packstone | ✓ | Taken | Yes | | | | | | | | |
| WM32 | Shale | | Taken | Yes | ✓ | | | | 12 | | | |
| WM33 | Wackestone | ✓ | Taken | Yes | | | | | | | | |
| WM34 | Wst /L. Mst | ✓ | Taken | Yes | | | | | | | | |
| WM35 | Shale | | Taken | Yes | ✓ | 54 | 18 | 130 | 4 | | | |
| WM36 | Packstone | ✓ | Taken | Yes | | | | | | | | |
| WM37 | Wst /Mst | ✓ | Taken | Yes | | 2 | 13 | 16 | | | | |
| WM38 | Wackestone | ✓ | Taken | Yes | | | | | | | | |
| WM39 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WM40 | Packstone | ✓ | Taken | Yes | | 1 | 2 | 24 | | | | |
| WM41 | Packstone | ✓ | Taken | Yes | | 1 | 8 | 3 | | | | |
| WM42 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WM43 | Packstone | ✓ | Taken | Yes | | | 8 | 12 | | | | |
| WM44 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WM45 | Pst /Gst. | ✓ | Taken | Yes | | | 5 | 36 | 1 | | | |
| WM46 | Mst /Gst | ✓ | Taken | Yes | | | | | | | | |
| WM47 | Wst./Mst | ✓ | Taken | Yes | | | | 6 | | | | |
| WM48 | Packstone | ✓ | Taken | Yes | | | | 11 | | | | |
| WM49 | Packstone | ✓ | Taken | Yes | | | | 17 | | | | |
| WM50 | Grainstine | ✓ | Taken | Yes | | | | | | | | |
| WM51 | Grainstine | ✓ | Taken | Yes | | | | | | | | |
| WM52 | Wackestone | ✓ | Taken | Yes | | | | | | | | |
| WM53 | Pst./Wst. | ✓ | Taken | Yes | | | | | | | | |
| WM54 | Mudstone | ✓ | Taken | Yes | | | 2 | 5 | | | | |
| WM55 | Packstone | ✓ | Taken | Yes | | | | | 1 | | | |
| WM56 | Packstone | ✓ | Taken | Yes | | | | | | | | |
| WM57 | Grainstine | ✓ | Taken | Yes | | | | | | | | |
| WM58 | Grainstine | ✓ | Taken | Yes | | | | | | | | |

# Appendix 1
## Methodology

| Sample No | Lithology | Thin Section | Photo | Processed | SEM | Planktonic | Small benthic | Larger foram | Ostracods | Radiolaria | Charophytes | Macro |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WM59 | Peloidal Gst | ✓ | Taken | Yes | | | | | | | | |
| WM60 | Peloidal Pst. | ✓ | Taken | Yes | | | 63 | 57 | | | | |
| P1 | Palaeosol | | | Yes | | | | | | 20 | 2 | |
| P3 | Palaeosol | | | Yes | | | | | | 120 | | |
| P4 | Palaeosol | | | Yes | | | | | | 41 | | |
| P5 | Palaeosol | | | Yes | | | | | | 14 | | |
| WM61 | Greywackes | ✓ | Taken | | | | | | | | | |
| WM62 | Greywackes | ✓ | Taken | | | | | | | | | |
| WM63 | Sandstone | ✓ | Taken | | | | | | | | | |
| WM64 | Sandstone | ✓ | Taken | | | | | | | | | |
| MW65a | Calcareous Sst | | | | | | | 2 | | 10 | 3 | |
| WM65b | Calcareous Sst | ✓ | Taken | | | | | | | 29 | 10 | |
| 30P2 | Palaeosol | | | | | | | | 1 | 4 | | |
| WM66 | Quartz arenite | ✓ | Taken | | | | | | | | | |
| WM67 | Sandstone | ✓ | Taken | Yes | | | | | | 11 | | |
| WM68 | Sandstone | ✓ | Taken | | | | | | | | | |
| WM68 | Quartz arenite | | Taken | | | | | | | | | |
| WM69 | Sandstone | ✓ | Taken | | | | | | | | | |
| WM70 | Sandstone | ✓ | Taken | | | | | | | | | |
| WM71 | Quartz arenite | ✓ | Taken | | | | | | | | | |
| WM72 | Quartz arenite | ✓ | Taken | | | | | | | | | |
| WM73 | Quartz arenite | ✓ | Taken | | | | | | | | | |
| WM74 | Greywackes | ✓ | Taken | Yes | | | | | | | | |
| WM75 | Quartz Sst | | Taken | | | | | | | | | |
| WME76 | Palaeosol/shal | | Taken | Yes | ✓ | 21 | | 55 | 11 | 25 | 1 | |
| WME77 | Palaeosol/Gst | | Taken | Yes | | | | | | | | |
| WME78 | Palaeosol | ✓ | Taken | Yes | | | | | | | | |
| WME79 | Palaeosol | ✓ | Taken | Yes | | | | | | | | |
| WME80 | Palaeosol | ✓ | Taken | Yes | | | | | | | | |
| WME81 | Palaeosol | ✓ | Taken | | | | | | | | | |
| WME82 | Palaeosol | ✓ | Taken | | | | | | | | | |
| WME83 | Palaeosol | ✓ | Taken | | | | | | | | | |
| WME84 | Palaeosol | ✓ | Taken | Yes | | | | | | | | |
| WME85 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME86 | Shale | | Taken | Yes | ✓ | 11 | 12 | 37 | 68 | | | |
| WME87 | Mudstone | ✓ | Taken | Yes | | | | | 56 | | | |
| WME88 | Shale | | Taken | Yes | ✓ | 8 | 13 | 35 | 52 | 3 | | |
| WME89 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME90 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME91 | Shale | | Taken | Yes | | | | | | | | |
| WME92 | Wst /Mst | ✓ | Taken | | | | | | | | | |
| WME93 | Grainstone | ✓ | Taken | Yes | | 46 | 85 | 11 | 120 | | | |
| WME94 | Shale | | Taken | Yes | ✓ | 43 | 55 | 125 | 187 | | | |
| WME95 | Shale | | Taken | Yes | ✓ | 7 | 41 | 111 | 74 | 23 | | |
| WME96 | Shale | | Taken | Yes | | | | | | | | |
| WME97 | Mudstone | ✓ | Taken | Yes | | 3 | 35 | 3 | 230 | | | |
| WME98 | Shale | | Taken | Yes | ✓ | 20 | 50 | 139 | 110 | 25 | | |
| WME99 | Shale | | Taken | Yes | ✓ | 10 | 96 | 55 | 102 | 11 | | |
| WME100 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME101 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME102a | Shale | | | | | | 2 | | | | | |
| WME102b | Mudstone | ✓ | Taken | Yes | | | | | 1 | | | |
| WME103 | Shale | | Taken | Yes | ✓ | 4 | | | 135 | 4 | | |
| WME104 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME105 | Mst /Wst | ✓ | Taken | Yes | | | | | | | | |
| WME106 | Shale | ✓ | Taken | Yes | | 2 | 7 | | 7 | | | |
| WME107 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME108 | Wackestone | ✓ | Taken | | | | | | | | | |
| WME109 | Mst /Wst | ✓ | Taken | | | | | | | | | |
| WME110 | Wackestone | ✓ | Taken | | | | | | | | | |
| WME111 | Shale/Mst | ✓ | Taken | Yes | | | 40 | 44 | 118 | 2 | | |
| WME112 | Wackestone | ✓ | Taken | | | | | | | | | |
| WME113 | Sandstone | ✓ | Taken | | | | | | | | | |

# Appendix 1
## Methodology

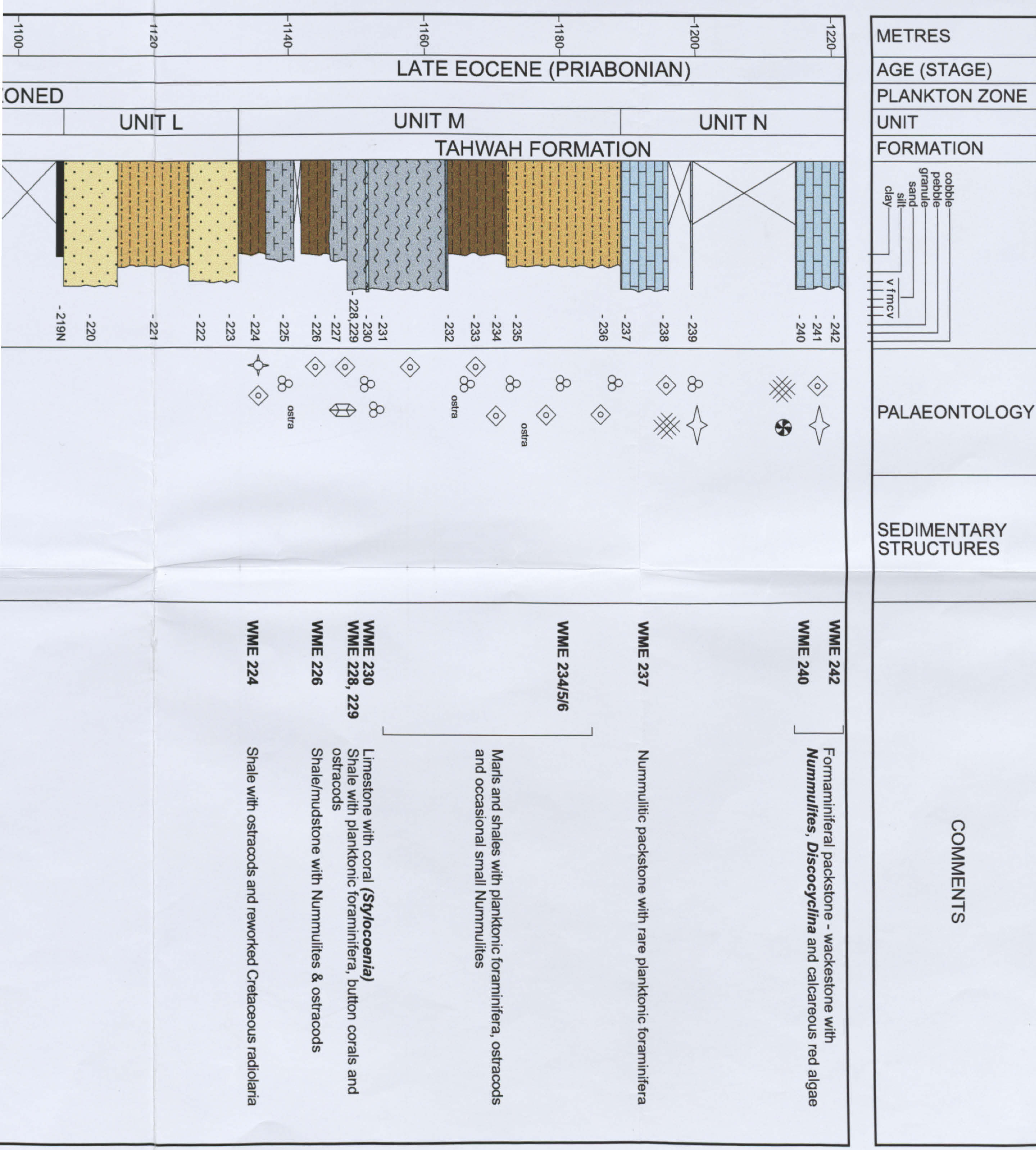
| Sample No | Lithology | Thin Section | Photo | Processed | SEM | Planktonic | Small benthic | Larger foram | Ostracods | Radiolaria | Charophytes | Macro |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WME114 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME115 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME116 | Siltstone | ✓ | Taken | Yes | | | | | 117 | 96 | | |
| WME117 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME118 | Siltstone | ✓ | Taken | | | | | | | | | |
| WME119 | Siltstone | ✓ | Taken | | | | | | | | | |
| WME120 | sandstone | ✓ | Taken | | | | | | | | | |
| WME121 | Siltstone | ✓ | Taken | | | | | | | | | |
| WME122 | Siltstone | ✓ | Taken | | | | | | | | | |
| WME123 | Siltstone | ✓ | Taken | Yes | | | 20 | | 18 | 4 | | |
| WME124 | Sandstone | ✓ | Taken | Yes | | | | 7 | 17 | 19 | | |
| WME125 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME126 | Sandstone | ✓ | Taken | Yes | | | | | | | | |
| WME127 | Sandstone | ✓ | Taken | | | | | | 7 | 131 | 1 | |
| WME128 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME129 | palaeosol | ✓ | Taken | | | | | | | | | |
| WME130 | Wackestone | ✓ | Taken | | | | | | | | | |
| WME131 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME132 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME133 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME134 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME135 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME136 | Siltstone | ✓ | Taken | Yes | | | 4 | | 82 | | | |
| WME137 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME138 | Siltstone | ✓ | Taken | Yes | | | 26 | 5 | 86 | 4 | 1 | |
| WME139 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME140 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME141 | Ankerite | ✓ | Taken | Yes | | | | | | | | |
| WME142 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME143 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME144 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME145 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME146 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME147 | Siltstone | ✓ | Taken | Yes | ✓ | 23 | 79 | 26 | 126 | 53 | | |
| WME148 | Siltstone | ✓ | Taken | Yes | ✓ | 54 | 154 | 221 | 45 | | | |
| WME149 | Siltstone | ✓ | Taken | Yes | | | | | | | | |
| WME150 | Siltstone | ✓ | Taken | Yes | | | 5 | | | 33 | | |
| WME151 | Sandstone | ✓ | Taken | | | | | | | 24 | | |
| WME152 | Calcareous Sil | ✓ | Taken | | | | | | | | | |
| WME153 | Calcareous Sil | ✓ | Taken | | | | | | | | | |
| WME154 | Pst /Wst. | ✓ | Taken | | | | | | | | | |
| WME155 | Pst /Wst | ✓ | Taken | | | | | | | | | |
| WME156 | Pst./Wst | ✓ | Taken | | | | | | | | | |
| WME157 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME158 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME159 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME160 | Rudstone | ✓ | Taken | | | | | | | | | |
| WME161 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME162 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME163 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME164 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME165 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME166 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME167 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME168 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME169 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME170 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME171 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME172 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME173 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME174 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME175 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME176 | Sandstone | ✓ | Taken | | | | | | | | | |

# Appendix 1
## Methodology

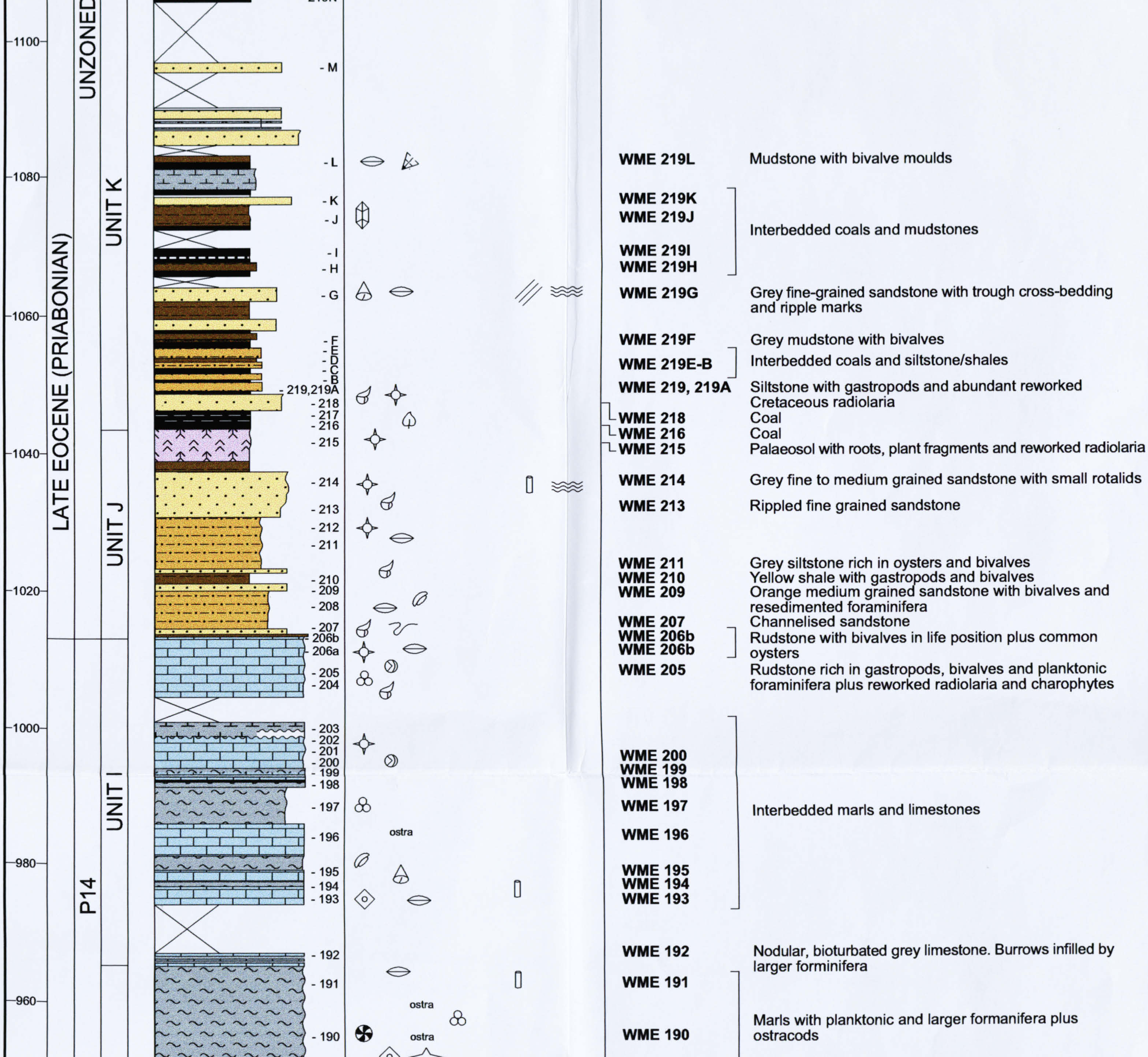
| Sample No | Lithology | Thin Section | Photo | Processed | SEM | Planktonic | Small benthic | Larger foram | Ostracods | Radiolaria | Charophytes | Macro |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WME177 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME178 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME179 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME180 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME181 | Marl | | Taken | Yes | | | | | | | | |
| WME182 | Marl | | Taken | Yes | ✓ | 2 | 150 | 230 | 22 | | | |
| WME183 | Marl | | Taken | Yes | ✓ | 32 | 20 | 249 | 63 | | | |
| WME184 | Marl | | Taken | Yes | | | 74 | 32 | 47 | | | |
| WME185 | Marl | | Taken | Yes | | | 22 | 37 | 6 | | | |
| WME186 | Marl | | Taken | Yes | ✓ | 17 | 16 | 21 | 12 | | | |
| WME187 | Barren | ✓ | Taken | Yes | | | | | | | | |
| WME188 | Barren | ✓ | Taken | Yes | | | | | | | | |
| WME189 | Barren | ✓ | Taken | Yes | | | | | | | | |
| WME190 | Packstone | ✓ | Taken | Yes | ✓ | | 57 | | 51 | | | |
| WME191 | Rudstone | ✓ | Taken | Yes | | | | | | | | |
| WME192 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME193 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME194 | Mudstone | ✓ | Taken | Yes | | | 30 | 38 | 56 | | | |
| WME195 | Wackestone | ✓ | Taken | | | | | | | | | |
| WME196 | Rudstone | ✓ | Taken | Yes | | | | | | | | |
| WME197 | Wackestone | ✓ | Taken | | | | | | | | | |
| WME198 | Marl | | Taken | Yes | | | | | | | | |
| WME199 | Marl/Lst | ✓ | Taken | Yes | | | | | | | | |
| WME200 | Grey Lst | ✓ | Taken | | | | | | 6 | | | |
| WME201 | Grey Lst | ✓ | Taken | | | | | | | | | |
| WME202 | Grey Lst | ✓ | Taken | Yes | | | | | | | | |
| WME203 | Grey Lst | ✓ | Taken | Yes | | | | | | | | |
| WME204 | Grey Lst | ✓ | Taken | | | | | | | | | |
| WME205 | Rudstone | ✓ | Taken | Yes | ✓ | 6 | | | 72 | 19 | 13 | |
| WME206 | Rudstone | ✓ | Taken | Yes | | | | | | | | |
| WME207 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME208 | Siltstone | ✓ | Taken | | | | | | | | | |
| WME209 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME210 | Shale | | Taken | Yes | | | | | | | | |
| WME211 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME212 | Siltstone | ✓ | Taken | Yes | | | | | | | | |
| WME213 | Sandstone | ✓ | Taken | Yes | | | | | | | | |
| WME214 | Sandstone | ✓ | Taken | | | | 27 | | | 2 | | |
| WME215 | Palaeosol | ✓ | Taken | Yes | | | | | | 7 | | |
| WME216 | Coal seam | ✓ | Taken | Yes | | | | | | | | |
| WME217 | Shale | ✓ | Taken | Yes | | | | | | | | |
| WME218 | Coal seam | | Taken | Yes | | | | | | | | |
| WME219 | Coal seam | ✓ | Taken | Yes | | | | | | 51 | | |
| WME219A | Coal seam | ✓ | Taken | Yes | | | | | | | | |
| WME219B | Coal seam | ✓ | Taken | Yes | | | | | | | | |
| WME219C | Siltstone | ✓ | Taken | Yes | | | | | | | | |
| WME219D | Coal seam | ✓ | Taken | Yes | | | | | | | | |
| WME219E | Coal seam | ✓ | Taken | Yes | | | | | | | | |
| WME219F | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME219G | Sandstone | ✓ | Taken | Yes | | | | | | | | |
| WME219H | Coal seam | ✓ | Taken | Yes | | | | | | | | |
| WME219I | Coal seam | ✓ | Taken | Yes | | | | | | | | |
| WME219J | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME219K | Sandstone | ✓ | Taken | | | | | | | | | |
| WME219L | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME219M | Coal seam | ✓ | Taken | Yes | | | | | | | | |
| WME219N | Coal seam | ✓ | Taken | Yes | | | | | | | | |
| WME220 | Sandstone | ✓ | Taken | | | | | | | | | |
| WME221 | Siltstone | ✓ | Taken | Yes | | | | | | | | |
| WME222 | Sandstone | ✓ | Taken | Yes | | | | | | | | |
| WME223 | Sandstone | ✓ | Taken | Yes | | | | | | | | |
| WME224 | Shale | | Taken | Yes | | | | 9 | 2 | 69 | | |
| WME225 | cal-rudite | ✓ | Taken | Yes | | | | | | | | |

# Appendix 1
## Methodology

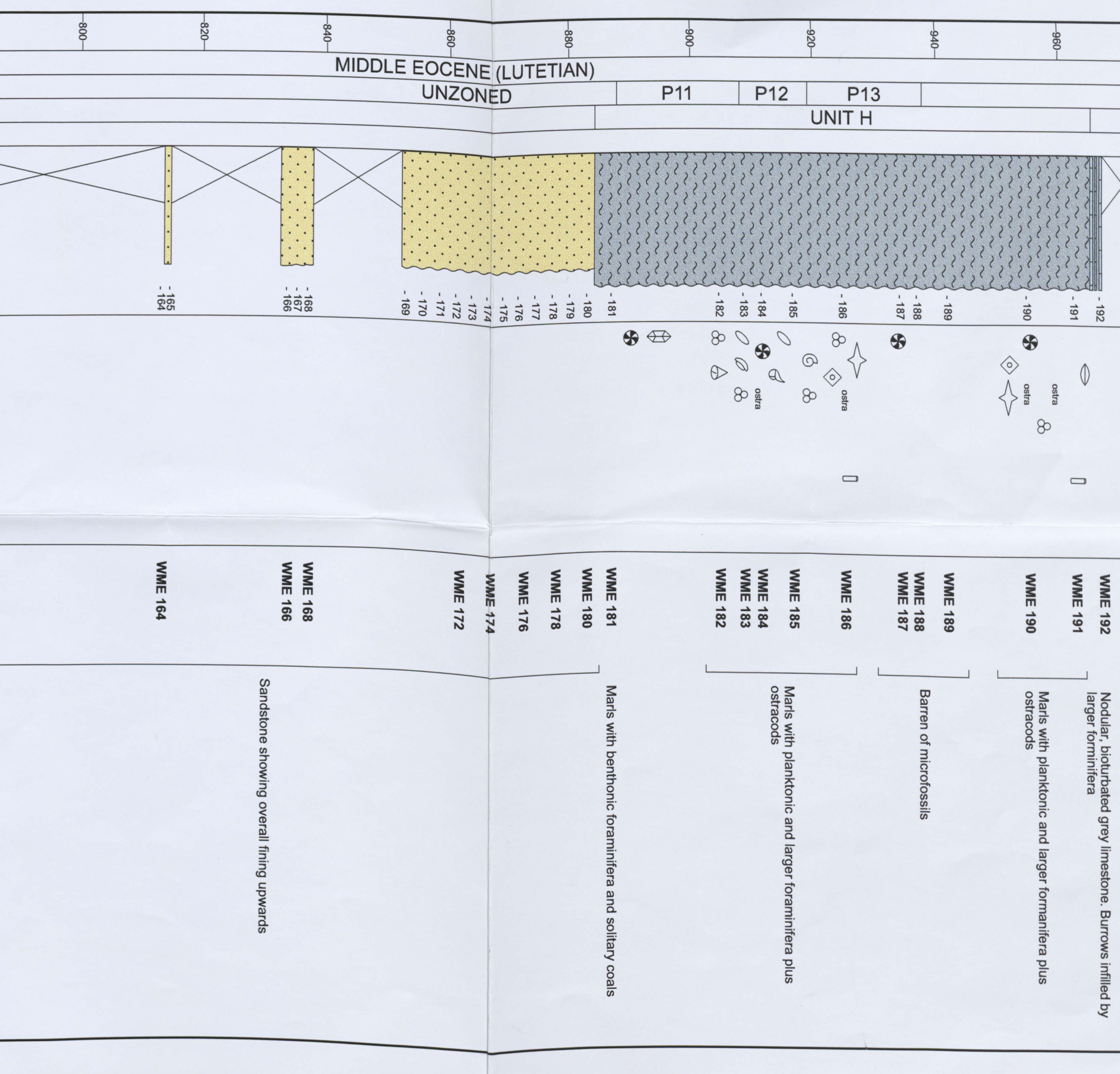
| Sample No | Lithology | Thin Section | Photo | Processed | SEM | Planktonic | Small benthic | Larger foram | Ostracods | Radiolaria | Charophytes | Macro |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WME226 | Mudstone | ✓ | Taken | Yes | | | | | | | | |
| WME227 | Marl | | Taken | Yes | | | | 45 | 68 | | | 12 |
| WME228 | Marl | | Taken | Yes | | 2 | | 260 | 56 | | | 4 |
| WME229 | Marl | | Taken | Yes | | 43 | 20 | 187 | 42 | | | 3 |
| WME230 | Limestone | ✓ | Taken | Yes | | 1 | 26 | 75 | | | | |
| WME231 | Marl | | Taken | Yes | ✓ | 15 | 14 | 22 | | | | 3 |
| WME232 | Limestone | ✓ | Taken | Yes | | | | | | | | |
| WME233 | Shale | | Taken | Yes | ✓ | 30 | | 165 | 37 | | | 3 |
| WME234 | Siltstone | ✓ | Taken | Yes | | | | | | | | |
| WME235 | Siltstone | | Taken | Yes | ✓ | 18 | | 90 | 39 | | | |
| WME236 | Siltstone | | Taken | Yes | ✓ | 35 | | 230 | 41 | | | |
| WME237 | Packstone | ✓ | Taken | Yes | ✓ | | | 6 | | | | |
| WME238 | Packstone | ✓ | Taken | Yes | | | | | | | | |
| WME239 | packstone | | Taken | Yes | ✓ | 4 | | 31 | | | | |
| WME240 | Pst /Wst | ✓ | Taken | | | | | | | | | |
| WME241 | Pst./Wst. | ✓ | Taken | | | | | | | | | |
| WME242 | Pst /Wst. | ✓ | Taken | | | | | | | | | |
| WS97 | Siltstone | ✓ | Taken | Yes | ✓ | 93 | | 215 | | | | |
| WS98 | Sandstone | ✓ | Taken | Yes | | | | | | | | |
| WS99 | Sandstone | ✓ | Taken | Yes | | | | | | | | |
| WS100 | Marl | | Taken | | | | | | | | | |
| WS101 | Sandstone | ✓ | Taken | | | | | 2 | | | | |
| WS102 | Sandstone | ✓ | Taken | | | | | | | | | |
| WS103 | Sandstone | ✓ | Taken | | | | | | | | | |
| WS104 | Marl | ✓ | Taken | | | | | 98 | | | | |
| WS105 | Sandstone | ✓ | Taken | | | | | | | | | |
| WS106 | Wackestone | ✓ | Taken | Yes | ✓ | 7 | | 127 | | | | |
| WS107 | Marl | ✓ | Taken | Yes | | | | | | | | |
| Totals | | 238 | | 169 | 30 | 678 | 1428 | 3362 | 2402 | 856 | 31 | 25 |



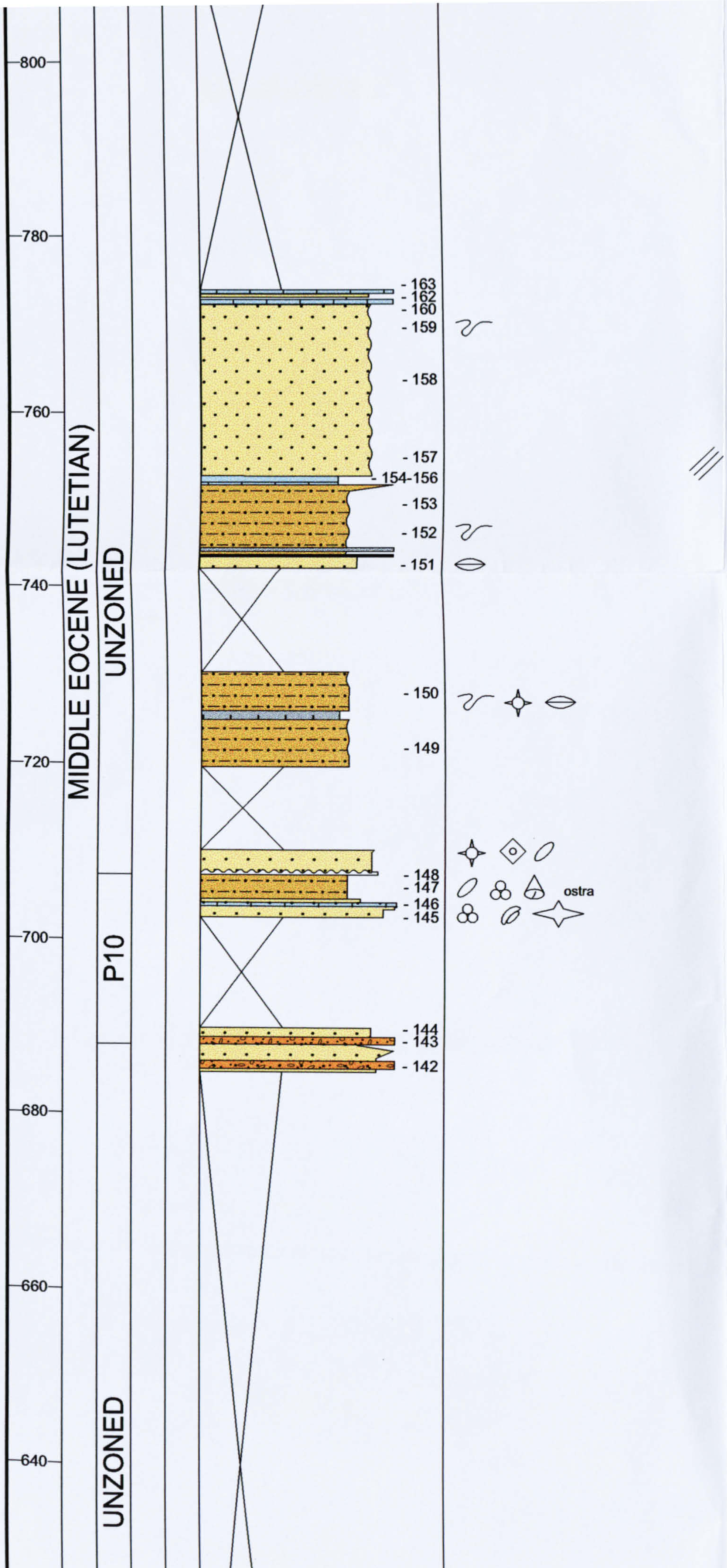
METRES
AGE (STAGE)
PLANKTON ZONE
UNIT
FORMATION
cobble
pebble
granule
sand
silt
clay
v f m c v
PALAEONTOLOGY
SEDIMENTARY STRUCTURES
COMMENTS
1100
1120
1140
1160
1180
1200
1220
LATE EOCENE (PRIABONIAN)
ONED
UNIT L
UNIT M
UNIT N
TAHWAH FORMATION
219N
220
221
222
223
224
225
226
227
228, 229
230
231
232
233
234
235
236
237
238
239
240
241
242
ostra
ostra
ostra
WME 242
WME 240
Formaminiferal packstone - wackestone with ***Nummulites, Discocyclina*** and calcareous red algae
WME 237
Nummulitic packstone with rare planktonic foraminifera
WME 234/5/6
Marls and shales with planktonic foraminifera, ostracods and occasional small Nummulites
WME 230
Limestone with coral ***(Stylocoenia)***
WME 228, 229
Shale with planktonic foraminifera, button corals and ostracods
WME 226
Shale/mudstone with Nummulites & ostracods
WME 224
Shale with ostracods and reworked Cretaceous radiolaria



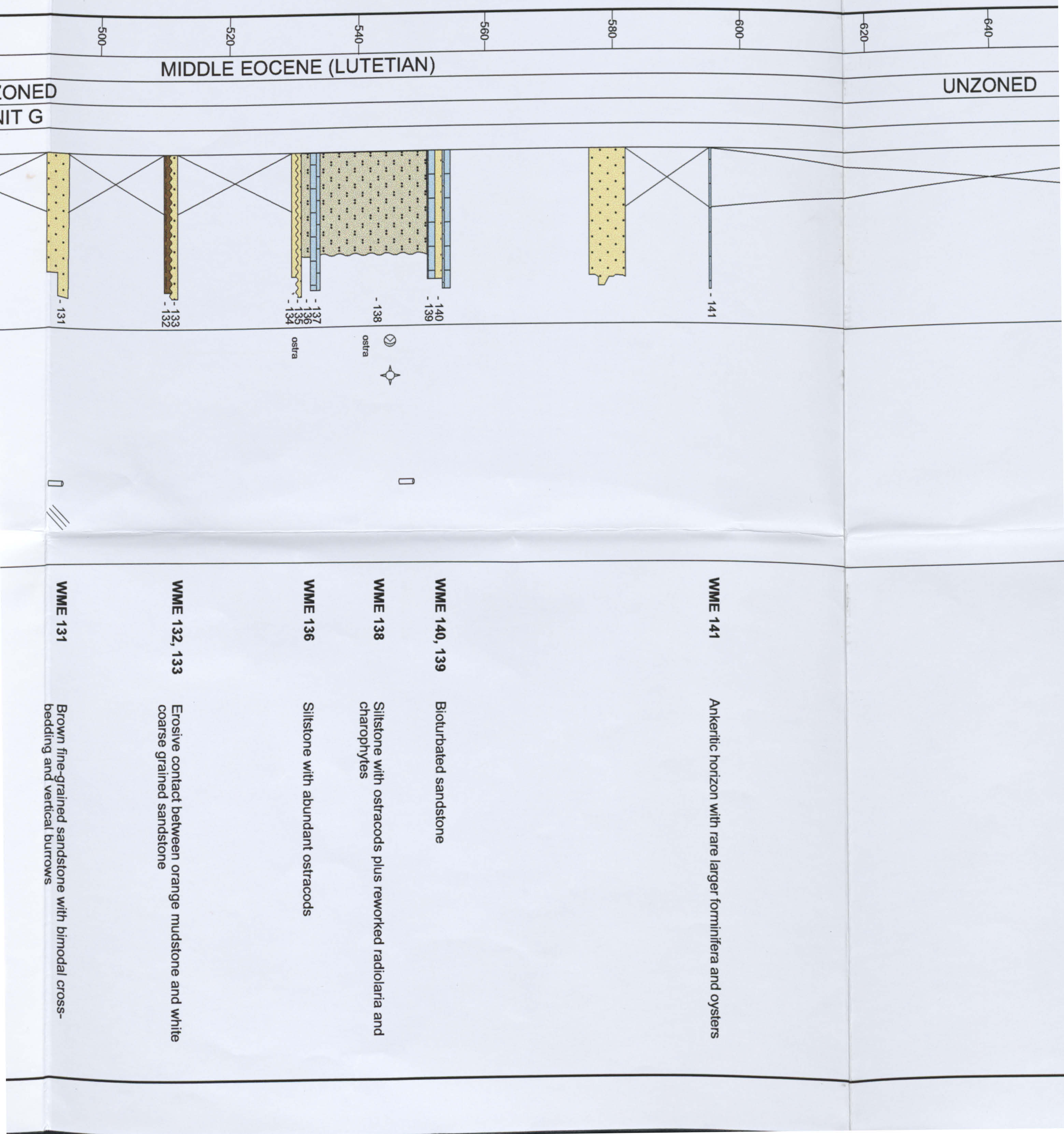
LATE EOCENE (PRIABONIAN)
P14
UNZONED
UNIT I
UNIT J
UNIT K
960
980
1000
1020
1040
1060
1080
1100
- M
- L
- K
- J
- I
- H
- G
- F
- E
- D
- C
- B
- 219,219A
- 218
- 217
- 216
- 215
- 214
- 213
- 212
- 211
- 210
- 209
- 208
- 207
- 206b
- 206a
- 205
- 204
- 203
- 202
- 201
- 200
- 199
- 198
- 197
- 196
- 195
- 194
- 193
- 192
- 191
- 190
ostra
ostra
ostra
WME 219L
Mudstone with bivalve moulds
WME 219K
WME 219J
WME 219I
WME 219H
Interbedded coals and mudstones
WME 219G
Grey fine-grained sandstone with trough cross-bedding and ripple marks
WME 219F
Grey mudstone with bivalves
WME 219E-B
Interbedded coals and siltstone/shales
WME 219, 219A
Siltstone with gastropods and abundant reworked Cretaceous radiolaria
WME 218
Coal
WME 216
Coal
WME 215
Palaeosol with roots, plant fragments and reworked radiolaria
WME 214
Grey fine to medium grained sandstone with small rotalids
WME 213
Rippled fine grained sandstone
WME 211
WME 210
WME 209
Grey siltstone rich in oysters and bivalves
Yellow shale with gastropods and bivalves
Orange medium grained sandstone with bivalves and resedimented foraminifera
WME 207
WME 206b
WME 206b
Channelised sandstone
Rudstone with bivalves in life position plus common oysters
WME 205
Rudstone rich in gastropods, bivalves and planktonic foraminifera plus reworked radiolaria and charophytes
WME 200
WME 199
WME 198
WME 197
WME 196
WME 195
WME 194
WME 193
Interbedded marls and limestones
WME 192
Nodular, bioturbated grey limestone. Burrows infilled by larger forminifera
WME 191
WME 190
Marls with planktonic and larger formanifera plus ostracods

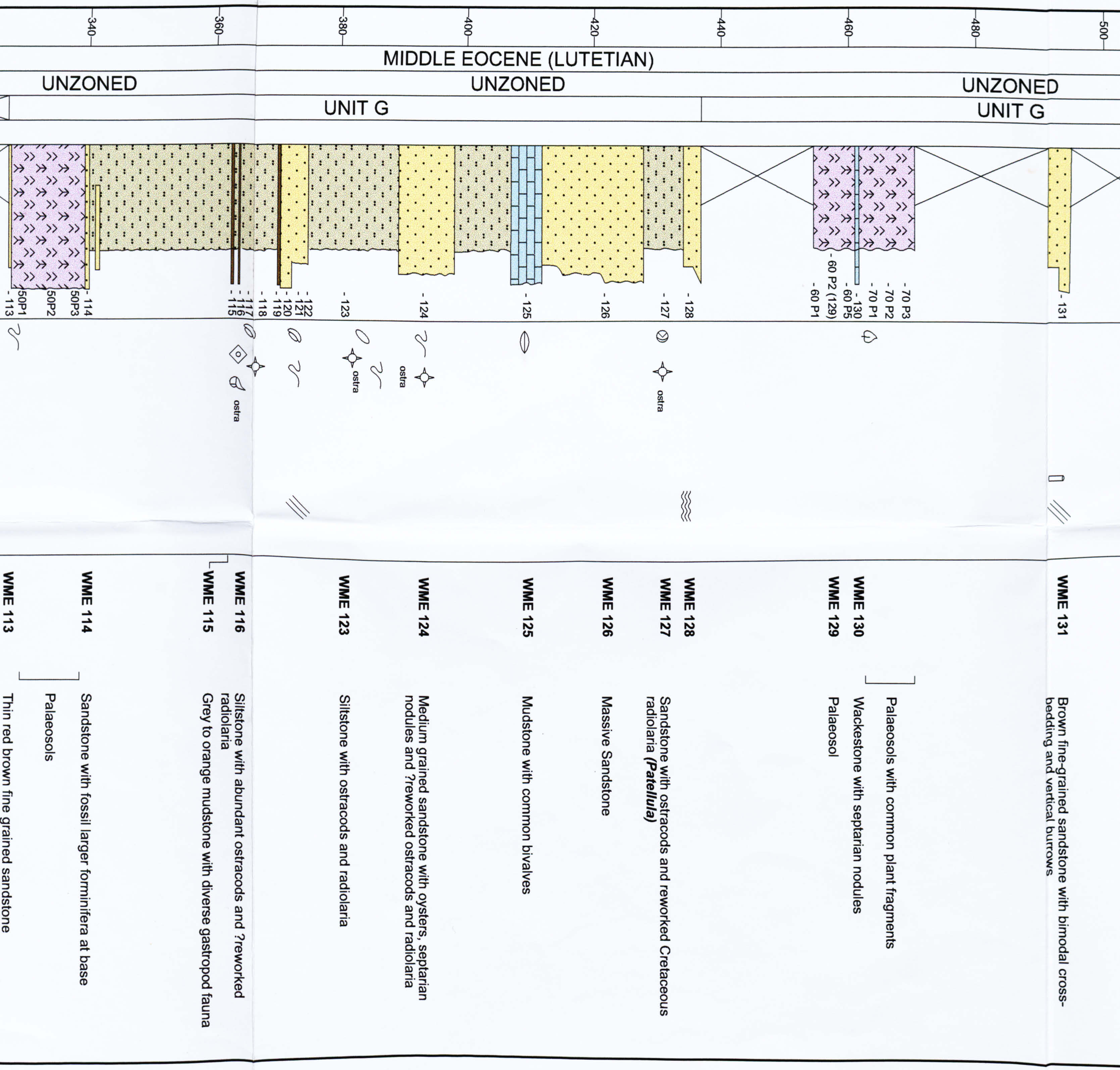


800
820
840
860
880
900
920
940
960
MIDDLE EOCENE (LUTETIAN)
UNZONED
P11
P12
P13
UNIT H
- 164
- 165
- 166
- 167
- 168
- 169
- 170
- 171
- 172
- 173
- 174
- 175
- 176
- 177
- 178
- 179
- 180
- 181
- 182
- 183
- 184
- 185
- 186
- 187
- 188
- 189
- 190
- 191
- 192
ostra
ostra
ostra
ostra
WME 164
WME 166
WME 168
WME 172
WME 174
WME 176
WME 178
WME 180
WME 181
WME 182
WME 183
WME 184
WME 185
WME 186
WME 187
WME 188
WME 189
WME 190
WME 191
WME 192
Sandstone showing overall fining upwards
Marls with benthonic foraminifera and solitary coals
Marls with planktonic and larger foraminifera plus ostracods
Barren of microfossils
Marls with planktonic and larger formanifera plus ostracods
Nodular, bioturbated grey limestone. Burrows infilled by larger forminifera

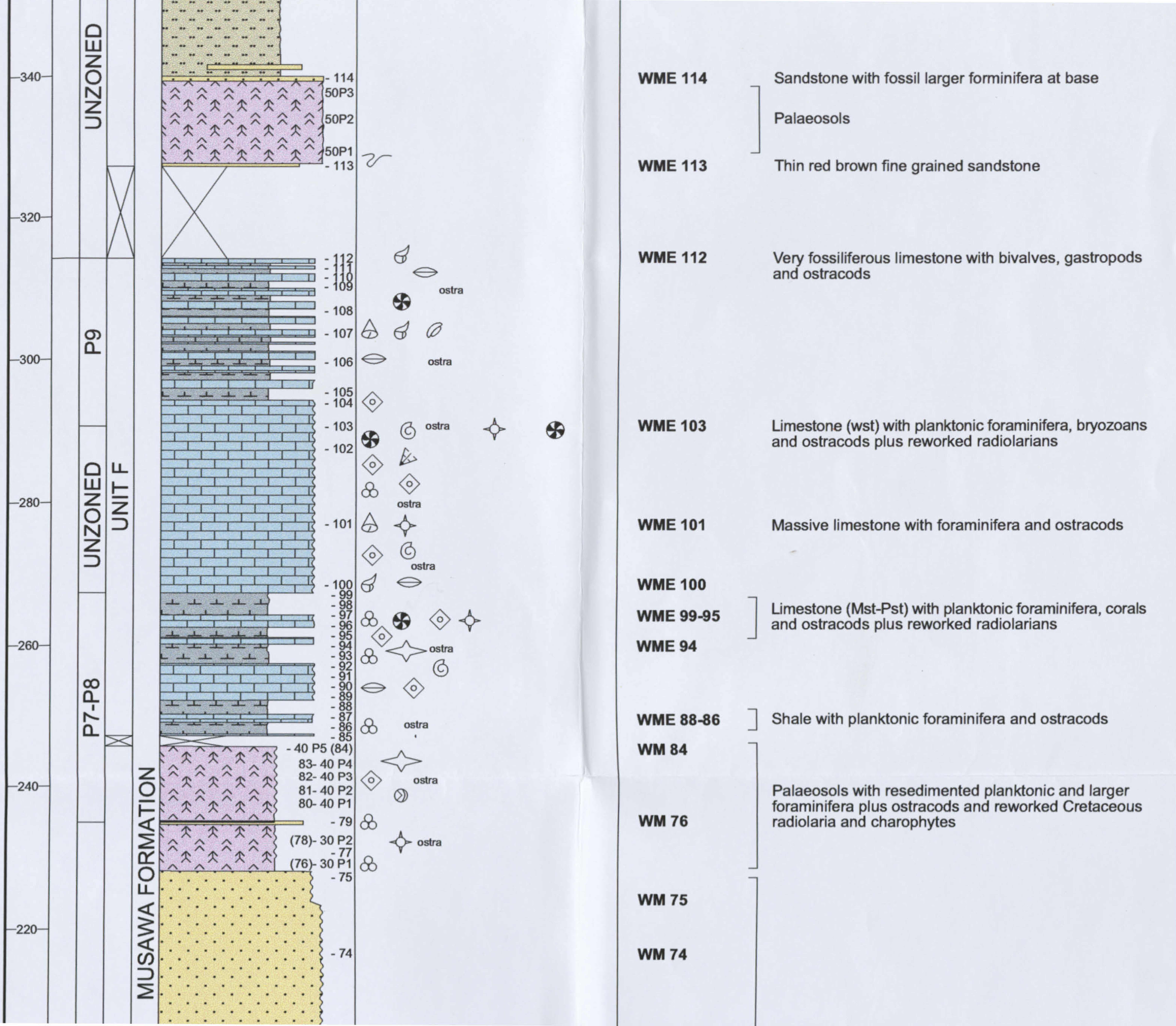



| | |
|---|---|
| WME 160 | Rudstone with oysters |
| WME 157-159 | Massive sandstone |
| WME 154-156 | Sandy bioturbated limestone with graded and cross-bedding |
| WME 153<br>WME 152 | Calcareous siltstone with oysters |
| WME 150 | Grey siltstone with oysters, bivalves and reworked radiolaria |
| WME 149 | White to purple siltstones with common secondary gypsum |
| WME 148<br>WME 147<br>WME 146 | Siltstone with planktonic and larger foraminifera plus ostracods. Reworked Cretaceous radiolaria |
| WME 142 | Brown medium grained sandstone with interbeds of conglomerate |

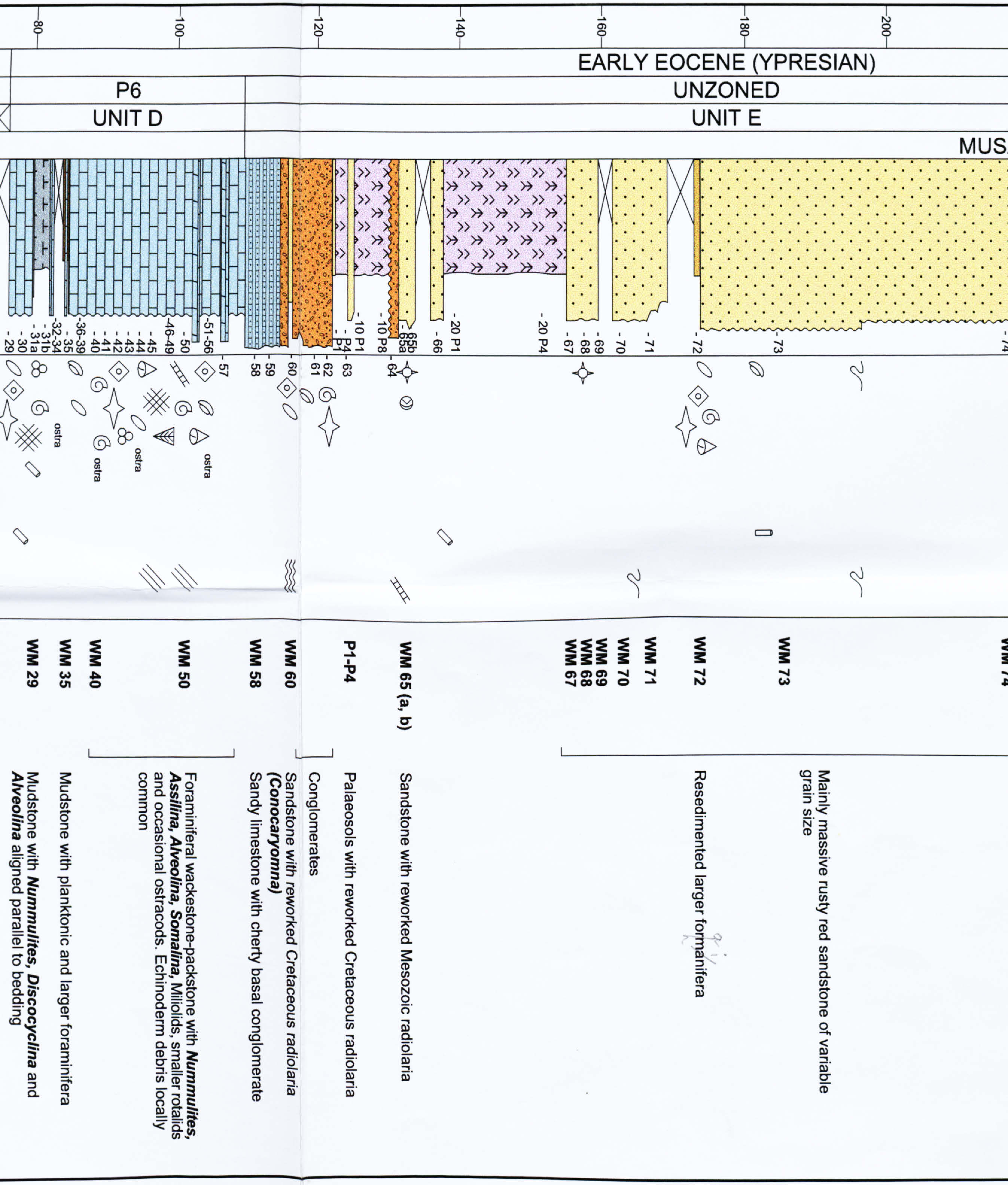

500
520
540
560
580
600
620
640
MIDDLE EOCENE (LUTETIAN)
ZONED
UNZONED
NIT G
131
133
132
137
136
135
134
138
140
139
141
ostra
ostra
WME 131
Brown fine-grained sandstone with bimodal cross-bedding and vertical burrows
WME 132, 133
Erosive contact between orange mudstone and white coarse grained sandstone
WME 136
Siltstone with abundant ostracods
WME 138
Siltstone with ostracods plus reworked radiolaria and charophytes
WME 140, 139
Bioturbated sandstone
WME 141
Ankeritic horizon with rare larger forminifera and oysters



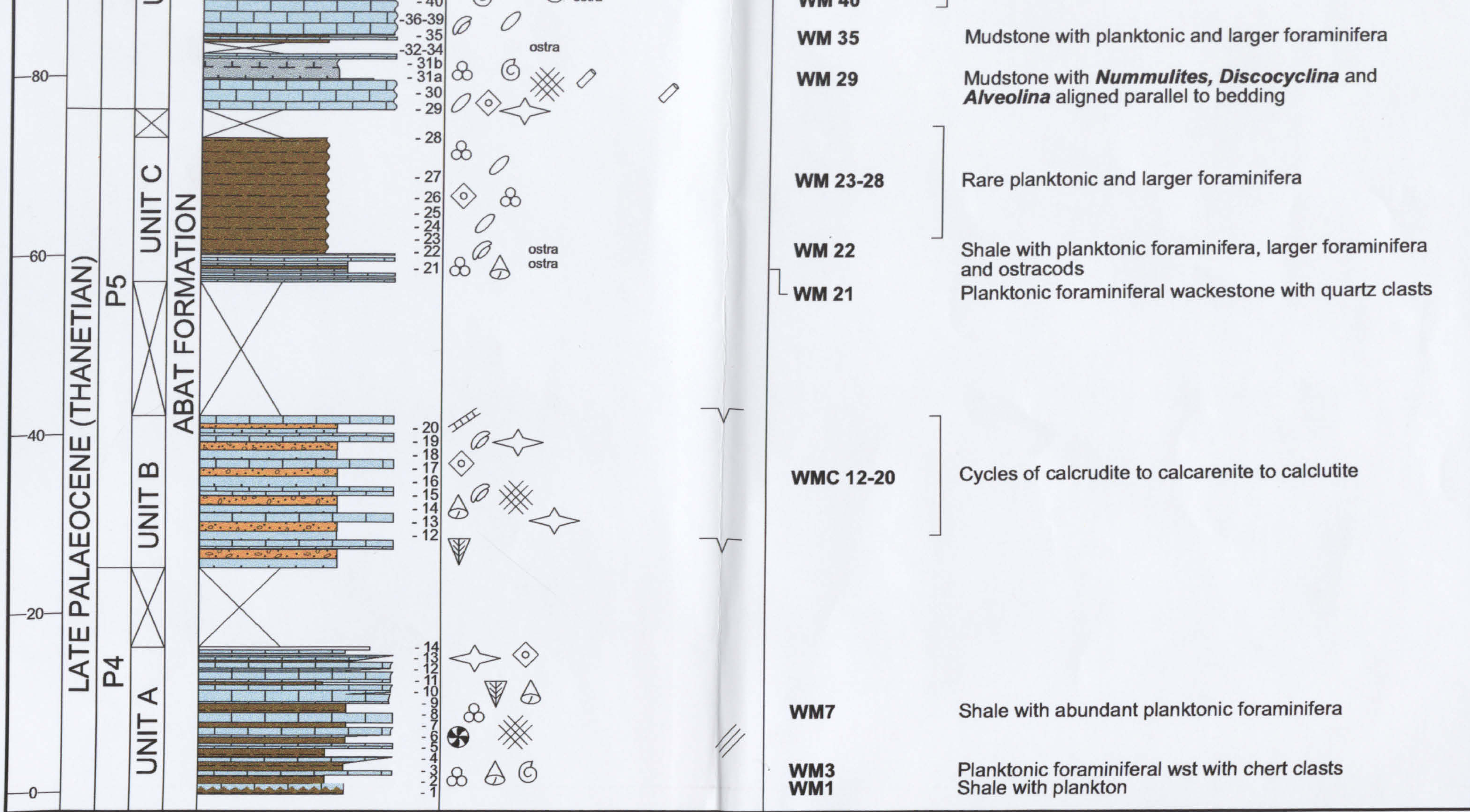
340
360
380
400
420
440
460
480
500
MIDDLE EOCENE (LUTETIAN)
UNZONED
UNZONED
UNZONED
UNIT G
UNIT G
- 113
50P1
50P2
50P3
- 114
- 115
- 116
- 117
- 118
- 119
- 120
- 121
- 122
- 123
- 124
- 125
- 126
- 127
- 128
- 60 P1
- 60 P2 (129)
- 60 P5
- 130
- 70 P1
- 70 P2
- 70 P3
- 131
ostra
ostra
ostra
ostra
WME 113
WME 114
WME 115
WME 116
WME 123
WME 124
WME 125
WME 126
WME 127
WME 128
WME 129
WME 130
WME 131
Thin red brown fine grained sandstone
Palaeosols
Sandstone with fossil larger forminifera at base
Grey to orange mudstone with diverse gastropod fauna
Siltstone with abundant ostracods and ?reworked radiolaria
Siltstone with ostracods and radiolaria
Medium grained sandstone with oysters, septarian nodules and ?reworked ostracods and radiolaria
Mudstone with common bivalves
Massive Sandstone
Sandstone with ostracods and reworked Cretaceous radiolaria (Patellula)
Palaeosol
Wackestone with septarian nodules
Palaeosols with common plant fragments
Brown fine-grained sandstone with bimodal cross-bedding and vertical burrows



340
320
300
280
260
240
220
UNZONED
P9
UNZONED
P7-P8
UNIT F
MUSAWA FORMATION
- 114
50P3
50P2
50P1
- 113
- 112
- 111
- 110
- 109
- 108
- 107
- 106
- 105
- 104
- 103
- 102
- 101
- 100
- 99
- 98
- 97
- 96
- 95
- 94
- 93
- 92
- 91
- 90
- 89
- 88
- 87
- 86
- 85
- 40 P5 (84)
83- 40 P4
82- 40 P3
81- 40 P2
80- 40 P1
- 79
(78)- 30 P2
- 77
(76)- 30 P1
- 75
- 74
ostra
WME 114
Sandstone with fossil larger forminifera at base
Palaeosols
WME 113
Thin red brown fine grained sandstone
WME 112
Very fossiliferous limestone with bivalves, gastropods and ostracods
WME 103
Limestone (wst) with planktonic foraminifera, bryozoans and ostracods plus reworked radiolarians
WME 101
Massive limestone with foraminifera and ostracods
WME 100
WME 99-95
Limestone (Mst-Pst) with planktonic foraminifera, corals and ostracods plus reworked radiolarians
WME 94
WME 88-86
Shale with planktonic foraminifera and ostracods
WM 84
Palaeosols with resedimented planktonic and larger foraminifera plus ostracods and reworked Cretaceous radiolaria and charophytes
WM 76
WM 75
WM 74



80
100
120
140
160
180
200
EARLY EOCENE (YPRESIAN)
P6
UNZONED
UNIT D
UNIT E
MUS
29
30
31a
31b
32-34
35
36-39
40
41
42
43
44
45
46-49
50
51-56
57
58
59
60
61
62
63
64
10 P1
P1
P4
10 P8
65a
65b
66
20 P1
20 P4
67
68
69
70
71
72
73
ostra
ostra
ostra
ostra
WM 29
WM 35
WM 40
WM 50
WM 58
WM 60
P1-P4
WM 65 (a, b)
WM 67
WM 68
WM 69
WM 70
WM 71
WM 72
WM 73
Mudstone with Nummulites, Discocyclina and Alveolina aligned parallel to bedding
Mudstone with planktonic and larger foraminifera
Foraminiferal wackestone-packstone with Nummulites, Assilina, Alveolina, Somalina, Miliolids, smaller rotalids and occasional ostracods. Echinoderm debris locally common
Sandy limestone with cherty basal conglomerate
Sandstone with reworked Cretaceous radiolaria (Conocaryomma)
Conglomerates
Palaeosols with reworked Cretaceous radiolaria
Sandstone with reworked Mesozoic radiolaria
Resedimented larger formanifera
Mainly massive rusty red sandstone of variable grain size




# KEY TO LITHOLOGICAL LOG

**Lithology**

- Limestone
- Sandy Limestone
- Calc-rudite
- Dolomite
- Marl
- Calcareous Shale
- Calc-arenite
- Sandstone
- Silt/Siltstone
- Shale/Mudstone
- Organic Shale
- Coal

**Microfauna**

- Alveolina
- Assilina
- Charophyte
- Discocyclina
- Miliolids
- Nummulites
- ostra Ostracods
- Planktonic foraminifera
- Radiolaria
- Small Rotaliids
- Textulariids

**Macrofauna**

- Bivalve
- Bryozoa
- Colonial coral
- Solitary coral
- Gastropods
- Oyster

**Other Constituents**

- Coralline algae
- Dascycladacean algae
- Plant fragments

**Sedimentary Structures**

- Cross bedding
- Erosive base
- Inclined burrow
- Vertical burrow
- Ripple marks

Calc-arenite

Sandstone

Silt/Siltstone

Shale/Mudstone

Organic Shale

Coal

Paleosol

Radiolaria

Small Rotaliids

Textulariids

Dascycladacean algae

Plant fragments

# Figure 3.2 (Encl.)

# Lithostratigraphic Column of the Wadi Musawa Section

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Exploration & Production